RED RIVER BASIN
COMMISSION

Report to the

International Joint Commission

on the Red River Basin Commission's

Wastewater Treatment Plant Optimization Project

15 March 2023

Executive Summary

The governments of Canada and the USA have approved the International Joint Commission recommendations for objectives and targets for nitrogen and phosphorus at the Red River international boundary to help address eutrophication concerns in the Red River and Lake Winnipeg. These targets and objectives are voluntary, and as such, every opportunity must be sought out to gain both large and small reductions in nutrient loading to the Red River.

The primary findings of this project are threefold, as follows:

1. Lagoons in the basin generally function as designed, any optimization efforts are unlikely to find major reduction unless they are not following their operational design or substantial changes to both infrastructure and operations occur.

2. Mechanical plants, unless they have been built in the last few years, have the potential to increase in optimization. Out of the six plants that were visited each of the five older plants could invest time and money to optimize nutrient removal and see improvements. Those opportunities vary between very low, moderate to significant costs and effort. Understanding how the municipality interprets its plant's lifecycle will play an important role in optimization efforts and capabilities.

3. Operators at these facilities are committed to improving water treatment work, however, in many cases they are not connected to information sources or encouraged to look at opportunities for improved performance. Continued educational opportunities for operators are a significant component of meeting the Binational Goals and Objectives.

Other key findings relate to best practices and performance improvements for lagoons and mechanical plants.

Lagoon Best Practices – Overall, all of the lagoons that were evaluated in the project were performing within the plants design criteria and meeting permit limits. On occasions when they did not meet permit limits, extenuating circumstances, primarily weather conditions, drove the discharge on a sub-optimal day. The following the steps listed below can assist an operator in avoiding the need to discharge on those sub-optimal days or employ low-cost methods to maintain more consistent performance.

1) **Sludge judge cells**. A fundamental component of each of these best practices is understanding how the system is operating. An article on how to sludge judge is included in this report in appendix B (page B-13). The process of sludge judging helps to understand how much sludge is on the bottom of the lagoon, where it is a thick or thin blanket, if there are preferential flow patterns for the water through the lagoon, and how much of the water column is available for nutrient removal activities.

2) **Quarterly water quality testing**: On a quarterly basis, perform intra-pond diagnostic bio-chemical oxygen demand (BOD), ammonia, and nitrate sampling between each treatment cell to understand the water chemistry of the wastewater lagoon systems. These analyses can assist the operator in understanding what is happening and where within the lagoon system. It can indicate

the need to consider some of the optimization steps listed in the next section (Lagoon Performance Improvements).

3) **Plan to desludge the treatment cells**. Sludge builds up and removal is a substantial expense. Budgeting and planning can help ensure it is completed at the right time and does not cause a budgetary crisis for small operations budgets.

4) **Closely monitor the trends in water quality permit parameters**. When operators determine that levels get close to permit limits, it is time to desludge. If the lagoon is not performing as designed there is a clear need to make changes in operations. There are some alternatives which can be identified through sludge judging and the most common remedy is sludge blanket mixing which is discussed in detail Appendix B (page B-27).

Lagoon Performance Improvements – Each lagoon system is designed differently and operates under different conditions. Food processing effluent or industrial wastewater can pose unique challenges; however, for the lagoons that were evaluated, the following provides some recommended changes.

1) Thief River Falls and Mahnomen recirculate water high in dissolved oxygen (DO) from later cells to the first cell for odor control and improved water quality. This activity would likely reduce ammonia significantly within the system in addition to the odor control benefit.

2) Breckenridge lagoon has historically had exceedances in total suspended solids (TSS) and pH. The primary cause for these exceedances is algae. Better selection of where to discharge from could reduce algae in the effluent and avoid exceedances. Pull discharge water from at least four feet below the surface of the water and one foot up off the bottom of the treatment cell, and one foot past the toe of the dike if possible. If operators perform quarterly diagnostic testing as suggested above, there is potential to discharge from a different cell as the algae is likely most prevalent at the end of the system.

3) Thief River Falls had three exceedances of TSS over the last five years. From data analysis, the operators suspect that some of that is analytical error based on influent measurements that are not reflective of actual conditions. A disciplined approach to collection of influent total suspended solids (TSS) and five-day carbonaceous biochemical oxygen demand (CBOD5) or more frequently sampling may identify that influent numbers are substantially higher than previously recorded levels. This would dramatically improve their TSS reduction ratio and avoid permit violations.

Mechanical Plant Best Practices

Nitrogen Removal

Cycle aeration equipment on and off provides alternating DO conditions for ammonia-nitrogen conversion to nitrate-nitrogen and low DO conditions for nitrate-nitrogen conversion to nitrogen gas. See Automation and testing equipment in Appendix C for more details.

On five, separate occasions, collect wastewater grab samples going into and out of each in-service aeration basin. Filter and test for ammonia, nitrate, and soluble Biological Oxygen Demand (BOD). And separately or concurrence with the sample collection, measure DO at the end of an air-on cycle and at the end of an air-off cycle in each of the in-service aeration basins. See Appendix C (pages 3, 7 & 9) for more details.

Shut off mixers in the anoxic zones for extended periods of time so that sludge settles and creates a greater oxygen demand in the sludge blanket thereby enhancing anoxic conditions, but don't allow any one area of the tank go without mixing for at least 15 minutes every few days as the settled sludge may begin to decay and release too many nutrients. See Appendix C (pages 9 & 19) for more details.

Phosphorus Removal

If aeration basins can be converted to sequencing batch reactors (SBRs), perhaps other tanks could be affordably repurposed as side stream fermenters for biological phosphorus removal. Another strategy is to install dividing walls in the existing aeration tanks to create anaerobic zones to serve as mainstream fermenters. See Appendix C (page 6) for more details.

Pump back a percentage of non-aerated sludge into the aeration tank. Sludge in the non-aerated sludge holding tanks can go septic and as it does phosphate accumulating organisms) that live in and with the mixed liquor need to (a) feed on volatile fatty acids in septic conditions and (b) multiply in aerobic conditions. Once the energized bacteria are pumped back into the aeration tank, they will multiply, and their population will increase. As they grow, they concentrate phosphorus inside their cells. As they are wasted back into the sludge tank and eventually hauled away, the phosphorus leaves with the sludge. Appendix C (page 12).

Aluminum products like Alum are highly reactive, 'large' molecule, that binds to organic material in suspended solids. These solids can contain large quantities of soluble phosphorus in the case of wastewater streams. The proper use of Alum can encourage the development of organic mats that eventually sink through gravity and can be removed with waste activated sludge. For facilities with low throughput and only minor phosporus reductions required for permit limit, this operational strategy can provide effective phosphorus removal; there is however significant expense for the alum as well as operator time and effort. Appendix C (pages 2 &10).

Mechanical Plant Performance Improvements

Each of the mechanical plants that were visited during this project, with the exception of the brand new facility in Selkirk Manitoba, has the potential to benefit from optimization activities. The two plants that are known to be taking steps to optimize are Gonvick and Halstead Minnesota.

Gonvick MN, has the potential to reduce nitrogen in its discharge but has a variety of challenges to doing so there are periods of the year that their permits are more restrictive based on surface water conditions. They intend to pursue the optimization later in 2023. When results are available an addendum to this report may be produced. See Appendix C (pages 8-10) for more details.

The Halstead facility was the most readily optimizable. For a small cost of roughly $20,000 (US) they were able to add timers that can automatically cycle the aeration system and purchase an water quality analytical device and testing supplies. Overall, the process of optimization has been fairly slow. The staff only works at the facility part time and works on other city utilities the rest of the time. The testing and recycling of waste to the headworks is cumbersome based on the design of the facility itself and the optimization has been ongoing for several months at the time of this report. If significant improvements are realized an addendum to this report will be published. See Appendix C (pages 11-13) for more details.

Acknowledgement

The role of the RRBC in this project has been to recruit participant facilities, provide administration and collaboration among the many partners. In addition, the RRBC is the primary author of this final report. However, the Project could not have been completed without the partnerships that the Red River Basin Commission values so highly. We would like to express our gratitude to the following:

The International Watersheds Initiative and International Joint Commission for funding this project and being extra flexible as changes occurred in the project due to the pandemic.

The U.S. Environmental Protection Agency for funding part of the effort and collaboration in scoping and identifying appropriate experts.

Grant Weaver of Clean Water Ops for his flexibility and can do attitude in working with mechanical treatment plants and the various agencies. His expertise and personable manner were crucial to the success of this project.
https://www.cleanwaterops.com/

Steve Harris of H & S Environmental for his outgoing nature and ability to communicate with all levels of knowledge holder and the functioning of Wastewater Lagoons. Each person that interacted with him commented that they never met someone with more ability to tach and coach on the subject.
https://www.facebook.com/people/HS-Environmental/100063642487324/

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Project Proposal

Background:

Note - The original project included the information below, since the project was slowed by the pandemic and other circumstances some statements in the project proposal section of this report are no longer accurate, I.e. "The International Joint Commission has recommended that the governments of Canada and the USA adopt objectives and targets for nitrogen and phosphorus…." These statements have not been changed in the Proposal section of the report.

The International Joint Commission has recommended that the governments of Canada and the USA adopt objectives and targets for nitrogen and phosphorus at the Red River international boundary to help address eutrophication concerns in the Red River and Lake Winnipeg. This proposal encourages basin-wide nutrient reductions from point sources by offering wastewater facility optimization technical assistance, workshops and on-site consultation for both mechanical plants and lagoons. The goal of the workshops and on-site assistance is to modify wastewater operations to achieve voluntary nutrient reductions. Additionally, the project report will identify best practices for replication at other facilities, supporting nutrient reduction throughout the Red River Basin

The technical assistance providers have a proven track record of working with lagoons and mechanical plants to achieve and document nutrient effluent reductions. The final report will summarize the nutrient effluent reductions achieved and include a list of best practices. This document will provide valuable information for other facilities in the basin to aid in their efforts to establish effective, low-cost practices to reduce nutrients. Information derived from the workshops and final report will expand the reach of the project to facilities throughout the Red River basin.

This project supports Components 3 and 5 of the IRRB's approved Nutrient Management Strategy including to "identify nutrient reduction actions and activities for the Red River watershed that could assist in achieving nutrient load allocations and/or water quality targets for nutrients" and to "facilitate ongoing technical, scientific and methodological dialogue and information sharing." The project has been designed to fulfill two of the Board's work plan priority actions to: 1) recommend appropriate strategies to the Commission concerning water quality, quantity and aquatic ecosystem health objectives in the basin; and 2) encourage the appropriate regulatory and enforcement agencies to take steps to ensure that agreed objectives are met.

This project supports consistent, multi-jurisdictional and binational efforts to help address eutrophication for the entire watershed, with Red River Basin Commission (RRBC) leadership and federal, state, and provincial involvement to provide an appropriate foundation for watershed scale prevention efforts. Optimizing the operations of wastewater facilities through workshops and technical assistance is a simple, effective and proven method for improving water quality and reducing costs that can be shared broadly throughout the basin.

Scope of Work and Objectives

The objectives of this project were:

1) Improve operator knowledge to address common challenges faced by lagoon systems.

2) Improve operations to decrease ammonia concentrations related to aerated and facultative lagoons located within the Red River watershed.

3) Reduce total nitrogen and total phosphorus loading associated with mechanical wastewater treatment plants to help achieve the voluntary nutrient objectives and targets established for the Red River and Lake Winnipeg; and

4) Improve operator understanding of methods and opportunities to reduce total nitrogen and total phosphorus effluent concentrations at mechanical plants while lowering energy expenditures incurred and operational costs at the plant.

5) Share optimization results and best practices widely with municipalities across the RRB. Any resulting products will be posted to the RRBC Website, promoted on RRBC social media, included in radio advertising and highlighted at one of the upcoming conferences (2021 or 2022 based on completion)

The tasks outlined in the scope of work were:

Task 1. Hold one optimization technical assistance workshop for mechanical plants Spring-Summer 2021

Task 2. Provide one-on-one technical assistance to 5-10 mechanical plants (Fall 2021-Spring 2022)

Task 3. Provide Project updates to International Joint Commission

Task 4. Hold two optimization technical assistance instructional sessions for lagoon systems at central RRB locations in Manitoba and Minnesota (Spring-Summer 2021)

Task 5. Provide one-on-one technical assistance to 6-7 lagoon facilities (Summer 2021-Fall 2021)

Task 6. Produce a final report that summarizes workshop results, identifies a list of best practices, and highlights performance improvements at specific facilities.

A full Communication Plan was to be developed pending project funding. Communication tasks could include:

- Publicize ND mechanical plant training and recruit facilities to participate (RRBC, NDDEQ, MPCA, MARD)
- Publicize MN lagoon training and recruit facilities to participate (RRBC, MPCA, NDDEQ, MARD)
- Recruit facilities (mechanical and lagoons) for on-site assistance
- Following on-site assistance track individual facility results (RRBC lead, Clean Water Ops, H&S)
- Summarize results (participation, effluent reductions, etc) in report (RRBC)
- Publicize report and share widely within RRB and with other transboundary watersheds (RRBC, IJC)

Project Adjustments

When the project was conceptualized and scoped it was anticipated that the pandemic was waning. As the project progressed it became clear that there were still many uncertainties, concerns, and restrictions. These challenges led to significant changes and adjustments in all the scope of work tasks except Task 1. The following provides explanation of the changes that were made to Tasks 2 through 6 to accommodate complications posed by the COVID 19 pandemic in 2021 and 2022.

Task 2. Provide one-on-one technical assistance to 5-10 mechanical plants (Fall 2021-Spring 2022)

- Changes made: Technical visits to mechanical plants could not be conducted until the border restrictions were relaxed and were completed in June of 2022.

Task 3. Provide Project updates to International Joint Commission

- Changes made: Two additional updates on the project were scheduled and held with the International Joint Commission in November of 2022 and February of 2023.

Task 4. Hold two optimization technical assistance instructional sessions for lagoon systems at central RRB locations in Manitoba and Minnesota (Spring-Summer 2022)

- Changes made: The initial lagoon workshop was postponed until September 2021 in Moorhead Minnesota. The Manitoba workshop was further delayed pending reduced border restrictions. During the delay the instructor encountered serious health issues and it was determined that neither he nor another instructor would be able to complete an additional workshop. Another concern was identified in that no meaningful recommendations for increased nutrient removal had been identified for any of the facilities that were visited in September of 2021. These changes led to revision of Task 5 and the addition of Task 5.1 to the project.

Task 5. Provide one-on-one technical assistance to 6-7 lagoon facilities (Summer 2021-Fall 2021)

- Changes made: Task 5 was amended to change the requirement for visits to six to seven (6-7) facilities to the four (4) facilities that were completed in September of 2021. The funds that were supposed to be expended on a Manitoba Workshop and visit to Manitoba Lagoons were diverted to Task 5.1.

Task 5.1. Facilitate optimization of one Mechanical Plant in the Basin (Late 2022-early 2023)

- Changes made: Task 5.1 included a demonstration of low cost potentially high impact optimization in a mechanical plant that had been visited already. In consultation with several partners, it was determined that Halstead Minnesota had the greatest likelihood of measurable reductions withing the available funding constraints.

Task 6. Produce a final report that summarizes workshop results, identifies a list of best practices, and highlights performance improvements at specific facilities.

- Changes made: Task 6 was scheduled to be complete in November of 2022. Due to the other changes to the project that end date was moved to March of 2023, specifically to facilitate inclusion of results from the Halstead Optimization.

Communication Plan

There were five key elements of communication that were identified by the partners as integral to the overall project.

1. Outreach to Operators: - Because the operators were scattered across two states (North Dakota, Minnesota) and the province of Manitoba, there is not a central location to communicate with them. Each jurisdiction was a little different. In North Dakota, the Department of Environmental Quality wanted to post registration opportunities to their website and send it to an email list. In Minnesota, the Pollution Control agency provided the list of operators that were listed on permits so the RRBC could mail directly. In Manitoba, the Association of Water and wastewater operators agreed to share the information with their membership through email.

2. Targeted Recruiting: Once information had been shared broadly, more deliberate contacts were made for recruiting purposes. The responsible agencies in each jurisdiction recommended some specific facilities that might be interested in participation. The targeted contacts were very important in identifying willing facilities for site visits.

3. Survey Questions: Each workshop included a few survey questions of the participants. The questions were primarily focused on instruction and previous knowledge of the topics presented.

4. The Red River Basin Commission, in cooperation with the contracted experts, was exclusively responsible for development of this report. Once the report is complete it will be posted on the RRBC Web site, shared with workshop participants and partners.

5. The written report will be submitted electronically on the completion of the entire scope of work. A presentation will be made at the RRBC annual conference in January 2024. The offer will be made at that time to share with other municipalities throughout the Basin.

6. The information and knowledge gleaned from the workshops will be available to operators in the region, with the goal of improving water quality throughout the basin. Where available, data capturing the changes in effluent quality will be summarized and shared in the report deliverable to this contract and made widely available to other operators and to local decision makers.

Project Outcomes

Mechanical Plant Webinars

Task 1 included conducting webinars for mechanical wastewater treatment operators. The 2-hour webinars were held one morning each week between 22 June 2021 and 27 July 2021. The specific dates and topics are listed in the table below.

Each of the webinars had at least 120 people signed-in, the software also monitored level of attention based on when the webinar was the top level of window open on a monitor. These webinars had more than 135 signed in virtually. Almost 80 operators across Minnesota were able to get continuing education credits and there were approximately 30 from North Dakota and 10 from Manitoba.

Several follow up exchanges have taken place between various participants and interest continues in seeing outcomes of optimization efforts across the region.

Table 1: Listing of Meetings/Webinars

Session	Date	Title
Session 1	Tuesday, June 22	Optimizing Nitrogen Removal in Activated Sludge WWTPs – Introduction/Overview
Session 2	Tuesday, June 29	Optimizing Phosphorus Removal in Activated Sludge WWTPs
Session 3	Wednesday, July 7	Optimizing Nitrogen and Phosphorus Removal in Activated Sludge WWTPs – Review
Session 4	Tuesday, July 13	Case Studies, Part 1
Session 5	Tuesday, July 20	Case Studies, Part 2
Session 6	Tuesday, July 27	Red River Participants' Wastewater Treatment Plants

Mechanical Plant Site Visits

Task 2 included providing one-on-one technical assistance to 6 mechanical plants throughout the basin. Those visits were completed in June of 2022 and detailed notes on each location can be found in Appendix C. For almost all the facilities there were recommendations for how more nutrient reductions could be achieved without major capital investment. The Selkirk facility is an exception since it is brand new and includes all the latest treatment options.

Table 2: Provide description

Location	**Date**
Fergus Falls, MN	13 June 2022
Halstad, MN	14 June 2022
Grand Forks, ND	14 June 2022
Portage la Prairie, MB	15 June 2022
Selkirk, MB	16 June 2022
Gonvick, MN	17 June 2022

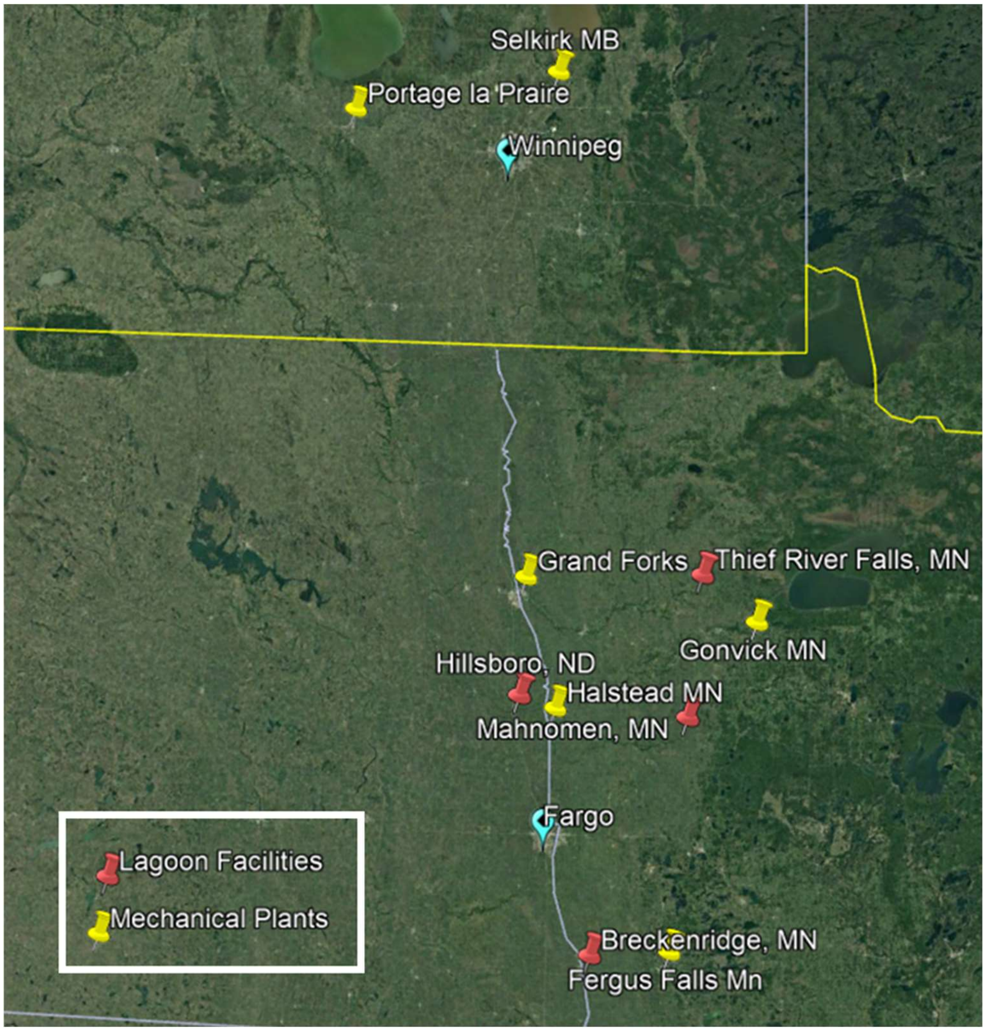

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Figure 1: Location of treatment facilities visited in connnection with this project

There were 2-5 operators involved in each site visit and they continued to engage Mr. Weaver, the expert on Mechanical plants from Clean Water Ops related topics and converse with other local operators on the potential for improved nutrient reductions. Each plant received advice on how they could improve operator understanding of methods and opportunities to reduce total nitrogen and phosphorus effluent concentrations at mechanical plants while lowering energy expenditures incurred and operational costs at the plant.

Fergus Falls MN already removes the majority of phosphorus but there is potential an opportunity to remove additional nitrogen through the cycling of aeration. Some additional testing and software upgrades would be required to make this adjustment. See Appendix C (pages 1-4) for more details.

Grand Forks facility is also under consideration for substantial upgrades. Currently there is little opportunity for improved phosphorus removal but similar to Fergus Falls the facility ay be able to remove additional nitrogen through cycling of aeration. See Appendix C (pages 5-7) for more details.

Gonvick MN, has the potential to reduce nitrogen in its discharge but has a variety of challenges to doing so there are periods of the year that their permits are more restrictive based on surface water conditions. They intend to pursue the optimization later in 2023. When results are available an addendum to this report may be produced. See Appendix C (pages 8-10) for more details.

The Halstead facility was the most readily optimizable. For a small cost of roughly $20,000 (US) they were able to add timers that can automatically cycle the aeration system and purchase an water quality analytical device and testing supplies. Overall, the process of optimization has been fairly slow. The staff only works at the facility part time and works on other city utilities the rest of the time. The testing and recycling of waste to the headworks is cumbersome based on the design of the facility itself and the optimization has been ongoing for several months at the time of this report. If significant improvements are realized an addendum to this report will be published. See Appendix C (pages 11-13) for more details.

Portage la Prairie MB also has the potential to reduce both phosphorus and nitrogen, however, doing so would be more expensive and involved than other facilities in the basin. They are in the process of designing a new facility so it may not be cost effective for them to attempt optimization at this time. See Appendix C (pages 17- 19) for more details.

Task 3. Provide Project updates to International Joint Commission

Because this task is primarily and administrative process discussion will be limited to confirming that the terms of the contract were satisfied by three formal status updates to the IJC by the RRBC as well as multiple informal exchanges between the parties.

US Lagoon Seminar

Tasks 4 and 5 were combined into one week-long seminar for the US side of the border. Fourteen operators from eight facilities around the basin participated in the seminars and at least one of the site visits. This represented one 16-hour instructional session for lagoon systems and four one-on-one technical assistance visits.

There were fourteen participants in the seminar from eight different facilities, with Breckenridge being a smaller facility and Thief River Falls being relatively large for the Red River Basin.

The schedule of the seminar and visits can be found in the table below. Remarks on the current operation of each facility can be found in Appendix A. Appendix B contains several previously published articles that provide valuable insight to operators even when the experts are not present. These articles can continue to be highlighted for facilities that are seeking to improve nutrient reductions in their discharge.

Table 3: Provide Description

Session	Date	Topic
Session 1	Monday September 21	Diagnosing Wastewater Lagoon Problems
Session 2	Tuesday September 22	Breckenridge MN, Lagoon Field Testing

Session 3	Wednesday September 23	Hillsboro ND, Lagoon Field Testing
Session 4	Thursday September 24	Thief River Falls MN, Lagoon Field Testing
Session 5	Friday September 25	Mahnomen MN, Lagoon Field Testing

Plant Optimization

Task 5.1 was an additional task that was added when Manitoba Lagoon Site Visits had to be cancelled to facilitate optimization of one Mechanical Plant in the Basin. In consultation with Grant Weaver of Clean Water Ops Inc, it was clear that the Halstead treatment plant was the best option for investment as the smallest infusion of cash would have the greatest impact out of the facilities he visited.

The first step in this process was to secure the approval of the Minnesota Pollution Control Agency. The regulations in Minnesota are strict and detailed. Ensuring that the facility stayed in compliance with the discharge permit was the highest priority. The general plan was more detailed monitoring of nutrient concentrations in the facility and recirculation of bacteria rich water and increased aeration to stimulate nutrient treatment. After the MPCA approved the concept at the end of August 2022, new testing equipment was ordered and took nearly a month to arrive. An additional two months were required to get timers delivered and installed on the aeration system in the facility. Optimization work was therefore not initiated until Mid-January.

While aeration cycling and waste recirculation has been ongoing for several months there has not been a conclusive change in discharge concentration. Clean Water Ops, the RRBC and Halstead utilities personnel continue to have phone and virtual meetings to identify any challenges to the optimization work and are hopeful that over the next several months changes will result in both nitrogen and phosphorus discharge reductions. When the results are conclusive an addendum to this report will be published.

Task 6. Produce a final report that summarizes workshop results, identifies a list of best practices, and highlights performance improvements at specific facilities.

Because this task is primarily an administrative process discussion will be limited to confirming that the terms of the contract were satisfied by three formal status updates to the IJC by the RRBC as well as multiple informal exchanges between the parties. While the original timeline was extended due to Covid restrictions internationally, this report completes the final administrative requirements.

Several follow up exchanges have taken place between various participants and interest continues in seeing outcomes of optimization efforts across the region.

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H&S Environmental, LLC.

- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization
- Training

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Date: October 30, 2021

Ted Priester
Executive Director
Red River Basin Commission
1120 28th Avenue N, Suite B
Fargo, North Dakota 58201

Re: Performance Evaluation of the Breckenridge Minnesota Wastewater Lagoon System

Ted,

Enclosed is the October 30, 2021, report for H&S Environmental's (H&S) performance evaluation of the Breckenridge Minnesota Wastewater Lagoon System

The purpose of this report is to identify operational conditions and practices that should prevail to keep the effluent of the Breckenridge Wastewater Lagoon System within permit limits.

Breckenridge and H&S Environmental, LLC (H&S) compiled all facility data, sludge depth data, and other field data used in this report.

The conclusions reached in this performance evaluation are based on six (6) primary data sources:

1) The results of intra-pond biological oxygen demand (BOD_5) testing by RMB Environmental Laboratories, Inc.
2) The analysis of six-point-five (6.5) years of DMR data from the US EPA ECHO database and Minnesota Pollution Control Agencies' Wastewater Data Browser
3) Field-testing of Ammonia, Nitrate, Alkalinity, Dissolved Oxygen, and pH results by the Breckenridge and H&S Environmental, LLC
4) Sludge judging results by Breckenridge and H&S Environmental, LLC
5) DEQ Permit # MN 0022900, April 1, 2021, to March 31, 2026
6) Sludge judging results from Interstate Engineering, Wahpeton North Dakota, August 2018

Performance Evaluation of the Breckenridge Minnesota Wastewater Lagoon System

The City of Breckenridge, Minnesota wastewater facility is located at
46 18 15.65N, 96 32 58.46W

Permit Number MN 0022900

October 30, 2021

Prepared for

The International Red River Board

Project Title:
Supporting the IRRB's Nutrient Management Strategy Through Workshops and Technical Assistance in the Red River Basin

Prepared by
H&S Environmental, LLC
Steve Harris, President

This document was prepared under contract with the IRRB

Disclaimer

This document assumes basic wastewater operations knowledge, skills, understanding, and compliance with applicable federal and State permit limits.

Acknowledgments

This performance evaluation was prepared with assistance from Ted Priester, Executive Director, Red River Basin Commission

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22, 23, & 24. Effluent Phosphorus Concentrations Going Down

25. Effluent Ammonia Concentrations Trending Up

26 & 27. R2 Value for TSS and BOD5 Denoting a close Relationship 28 & 29. Influent Raw Sewage and Flow In Trending Down

28. Exceedances by Date and Type
29. Exceedances by Type, Number, and Percent Occurrence

Figure 1. The Five Cell Breckenridge Minnesota, Facultative Wastewater Lagoon System

Executive Summary:

This report will focus on the results of field nutrient testing by H&S Environmental, sludge judging by Interstate Engineering, H&S and Breckenridge, laboratory analysis by RMB Laboratories, Inc, as well as 6.5 years of DMR data from the US EPA ECHO database and Minnesota Pollution Control Agency's Wastewater Data Browser for recommendations on optimizing the Breckenridge wastewater lagoon system.

Because there was no flow on the day of Field testing, field and laboratory samples were taken directly from the influent and effluent sides of each treatment cell. The data from these samples show that final effluent BOD_5 and TSS are compliant and within permit limits. Effluent Ammonia measured 0.70 mg/l and Ortho Phosphorous was measured 3.8 mg/l. Dissolved oxygen before sunrise in Cell # 1 was over one-and-a-half (1.5) mg/l on the day of field testing.

The primary ammonia removal pathway appears to result from nitrification, but volatilization through high pH and assimilation by algae also remove ammonia. There is a one-hundred and seventy-five (175) day retention time at Breckenridge if water levels remain at three (3) feet giving the water time to exhaust nutrients producing clean water.

If Breckenridge were required to discharge on the day of field testing and sampling, it would meet permit limits for $CBOD_5$ and TSS.

Field testing of Dissolved Oxygen (DO) showed sufficient DO concentrations in all Cells for $CBOD_5$, TSS, and Ammonia removal.

Ammonia and Ortho-phosphorous showed progressive reduction through all five (5) cells of the treatment system.

No treatment cells require sludge removal at this time. Cell # 1 should be sludge judged again in three (3) years to estimate sludge accumulation rate and to determine when sludge will reach eighteen (18) inches in thickness. Because laboratory results show CBOD and TSS rise in Cell # 4, Cell # 4 should be sludge judged again soon. Sludge should be removed when it reaches eighteen (18) inches thick or when effluent water quality approaches permit limits. Sludge has accumulated in Cell # 1 to an average of 1.1 to 1.42 feet and Cell # 2 to 1.08 feet. Cell # 3 accumulated sludge to 0.86 feet. These numbers are based on a sludge profile performed by Energy Laboratories in August 2018.

Analysis of six-point-five-years (6.5) years of DMR data show thirty-five (35) permit violations occurred on seven (7) different days of discharge. All violations can be attributed to excess algae growth and the discharge of too many algae cells. There is a strong statistical correlation between TSS (algae cells) and $CBOD_5$, meaning that if TSS were lowered, $CBOD_5$ would also be lower. The relationship between TSS and $CBOD_5$ is so close; effluent $CBOD_5$ can be predicted based on the level of effluent TSS.

Thank you.

Sincerely,

Steve Harris
President
H&S Environmental, LLC

Figure 2. Steve Harris of H&S and Jeff Kugler with Breckenridge Sludge Judging Cell # 1

PERFORMANCE EVALUATION REPORT

Facility Name: The City of Breckenridge Minnesota Wastewater Lagoon System

Client: The City of Breckenridge, Minnesota, and The International Red River Board (IRRB)

Date of Field Sampling: September 21, 2021

Data Review:
Dissolved Oxygen, pH, Ammonia and Sludge Field Sampling Results
Intra-Pond BOD and Ammonia, RMB Labs, September 2021
Field Dissolved oxygen, pH, Temperature, Ammonia, Nitrate, Nitrite, and alkalinity, and sludge blanket thickness by Breckenridge and H&S Environmental, LLC, September 21, 2021
US EPA ECHO DMR date from April 2016 to April 2021
Sludge Blanket Profile by Interstate Engineering, august 2018
Permit: NPDES Permit No. MN0022900

Breckenridge, Minnesota:

Neil Crocker, Director of Public Works
Jeff Kugler, Operations Supervisor

The International Red River Board:

Mr. Ted Priester, Executive Director

H&S Environmental, LLC: Steve Harris, President, Mesa, AZ

Report Prepared By:
Steve Harris,
President, H&S Environmental, LLC
October 30, 2021

Section 1

Introduction and Background

1.0 Scope and Purpose

In September 2021, H&S Environmental and Ted Priester met at the Breckenridge wastewater lagoon system to test the system's water quality and take samples for RMB Lab testing. After thoroughly reviewing Breckenridge's field, lab, and DMR data, Steve Harris of H&S Environmental, LLC (H&S) prepared this performance evaluation.

The information used in this performance and optimization evaluation includes the following:

- In-person interviews with Jeff Kugler, Operation's Manager of Breckenridge, Minnesota, on the history and general condition of the lagoon system
- Analysis of 2015 through 2021 DMR data from the Wastewater Data Browser, MNPCA
- The results of intra-pond nutrient sampling, dissolved oxygen sampling, sludge judging by H&S, Breckenridge, and Intra-pond BOD_5 testing by RMB Labs.
- Sludge Profile of Cells 1 – 4 by Interstate Engineering, August 2018

The purpose of this evaluation is to identify ways to improve the treatment process to meet permit limits in a long-term sustained manner.

This report will focus on methods to keep the Breckenridge system within permit limits. To determine if in-pond optimization is possible, H&S Environmental will analyze and evaluate lagoon system performance with respect to (i) historical data reviewed, (ii) additional data gathered from field testing and sampling, and (iii) a review of sampling and testing protocols practiced by Breckenridge Minnesota utility personnel.

This report covers the Breckenridge Lagoon System performance as it existed up to September 2021.

Findings

Section 2 – Findings

2.0 Findings

The results of intra-pond sampling performed by H&S and Breckenridge (September 21, 2021) are presented below.

1. Laboratory analysis by RMB Labs shows Effluent BOD_5 was six (6) mg/l

2. Laboratory analysis by RMB Labs shows Effluent TSS was eleven (11) mg/l

3. Effluent Ammonia tested 0.70 mg/l in the field by H&S Environmental, LLC

4. Effluent Ortho-Phosphorous measured 3.8 mg/l in the field by H&S Environmental, LLC

5. Dissolved Oxygen measured in the morning, before the production of oxygen through photosynthesis, measured between 0.73 and 2.24 mg/l in Cell # 1. In Cell # 2, Dissolved Oxygen measured between 3.21 and 4.28 mg/l. In Cell # 3, predawn DO measured 4.95 to 5.18 mg/l.

6. Long retentions times, algae assimilation, and volatilization due to high pH, along with nitrification, are the major ammonia removal pathways. Nitrification appears to play a role in ammonia removal at Breckenridge due to the reduction of ammonia and alkalinity in Cells 1 & 2 and an $NBOD_5$ (BOD_5 – $CBOD_5$) of 44 mg/l in Cell # 1 effluent and 40.4 mg/l in the Cell # 2 effluent. $NBOD_5$ is considered the relative number of nitrifying bacteria in a system and denotes a system's ability to remove ammonia through nitrification. BOD_5 and TSS increase from Cell # 3 to Cell # 4, suggesting feedback from the sludge blanket. This should be investigated further.

7. pH as measured during the morning was within permit limits.

8. Sludge averaged 1.1 to 1.46 feet in Cell # 1 and 1.07 feet in Cell # 2, 1.06 in Cell # 3, and 0.856 in Cell # 4. Sludge volume in Cell # 1 is estimated to be 28,850,120 gallons. In Cell # 2, there are An estimated 2,650,001 gallons of sludge, Cell # 3: 2,645,587, and Cell # 4: 2,086,820 gallons.

9. Retention time, assuming accumulated sludge and NO short-circuiting is one-hundred-seventy-five (175) days. Calculated retention time is based on a flow of 0.32 gallons/day (6.5 years of DMR Data submitted by Breckenridge) and measured water depths in Cell # 1 and estimated depths in Cells 2 - 4.

10. The Trend in Influent Monthly Average Flow is increasing.

11. The Trend in Effluent pH for the 18- and 22-Acre Ponds is down.

12. There is an Upward Trend in effluent mass and concentration-based measures of Total Phosphorous. Monthly Average effluent $CBOD_5$ and TSS is trending down.

13. Statistically, TSS and BOD_5 are correlated. Efforts to lower one will lower the other.

14. Loading to the system appears to be normal for a shallow pond system in Minnesota: 4.8 to 8.4 lbs./acre/day based on 0.329 MGD and an average CBOD of between 144 (DMR data) - 250 mg/l.

15. There have been thirty-five (35) permit violations in seven (7) days over six-point-five (6.5) years. All of Breckenridge's violations are the result of algae growth

Section 3 – Recommendations - Continued

RECOMMENDATIONS

Based on the analysis of Intra- Pond field sampling results and the analysis of DMR data, below are recommendations for improved stabilization pond performance for long-term sustained compliance using the existing wastewater stabilization pond system.

The object of the recommended changes to the Breckenridge wastewater lagoon system is intended to keep Breckenridge permit compliant in a long-term sustainable manner.

Four (4) recommendations for the Breckenridge Minnesota wastewater lagoon system are:

1) Discharge as few algae cells as possible and no ammonia
2) Prepare now for desludging the treatment cells
3) Keep a close eye on the upward trends in CBOD, TSS, and pH. Increasing trends suggest sludge accumulation past eighteen (18) inches. Desludge when these numbers approach permit limits
4) Quarterly perform intra-pond diagnostic BOD, CBOD, TSS, Ammonia, and Nitrate to monitor the success of any changes. Remember, the lagoon system is subject to seasonal changes in the water temperature and length of the day. Therefore look to yearly changes in pond behavior for the success of any changes.

1) Discharge as Few Algae Cells as Possible and No Ammonia

All permit violations have been for TSS and pH exceedances from the effluents of the 18 and 22-acre ponds. Five (5) out of the thirty-five (35) permit violations have been from the 18-acre pond, and thirty (30) violations have been from the twenty-two (22) acre pond. Except for four (4) pH violations, all violations have been for effluent TSS exceedances as a result of excess algae growth.

There are several ways to control algae (TSS).

1) Multiple celled lagoon systems are designed by engineers to discharge from other than the last treatment cell during the summer. Hot weather and sunlight with long retention times support algae growth. Before a discharge, test the TSS coming out of Cells 2, 3, 4, and 5. Discharge from the cell having the lowest TSS and pH. During the winter, the treatment cells can return to series operation. Discharging from Cells 2, 3 or 4 may mean lower TSS.
2) Make sure there is no sludge feeding algae growth in Cell # 4; desludge if needed
3) Mixing/agitation has been shown to lower TSS. Lower TSS occurs by breaking up stratified water responsible for increased algae growth. Mixing/agitation also increases turbidity, reducing algae growth
4) Lower the level of the effluent draw-off. Algae grow in the upper three (3) feet of the water column, where algae have the greatest access to sunlight. There may be fewer algae cells below the "photic zone" at the four-foot (4) level. Ensure discharge is from the lowest possible level in the treatment cell without picking up sludge particles at the bottom of the cell.
5) Chemical control. Try this only as a last resort. If you do go with chemical control, check with the State
6) Sand filtration works! The US EPA recommends sand filtration in their latest lagoon manual. Sand filtration can remove up to seventy-nine (79) percent of the effluent TSS and BOD.

2) Begin Now to Plan for Desludge Cell # 1

Sludge has accumulated to 1.1 to 1.46 feet in Cell # 1. Typically sludge is removed when it reaches 1.5 feet to avoid benthal feedback…the feeding of algae cells with nutrients released from the sludge blanket diminishing water quality.

Section 3 – Recommendations - Continued

Laboratory results show thirty-seven-point eight (37.8) percent BOD removal from Cell # 1. BOD removal should be at least eighty (80) percent from Cell # 1 for the latter cells to remove nutrients. It takes until Cell # 5 to get TSS removal to within permit limits. Look at Figure xx. There is an increase in $CBOD_5$ and TSS in Cell # 4. This increase may be caused by accumulated sludge feeding algae cells, causing increased TSS and pH. Re-sludge judge Cell # 4. Rural Water may help here.

Intra-pond testing is how to discover where the TSS and problems are occurring.

At current water levels, sludge in Cell # 1 occupies thirty-seven (37) percent of Cell # 1's treatment capacity leaving a one-point-forty-five (1.45) foot water cap to treat the incoming waste.

Effluent TSS is compliant at 11 mg/l and CBOD at 3.67 mg/l. The release of nutrients from a sludge blanket can feed algae growth causing high effluent TSS and CBOD. There are downward trends in influent and effluent TSS, CBOD, pH, and a slight increase in effluent Total Phosphorous.

3) **<u>Keep an Eye on Increasing Trends in Effluent TSS, BOD, and pH</u>**

Increasing trends in effluent BOD, TSS, pH, and Phosphorous are signs of benthal feedback; the release of nutrients by a sludge blanket causes algae growth leading to TSS, $CBOD_5$ violations, and problems with diminishing percent removal efficiency. Watch these numbers closely.

4. **<u>Quarterly Perform Intra-pond Diagnostic BOD, TSS, Ammonia, and Nitrate to Monitor the Success of Any Changes.</u>**

Intra-pond testing is how to evaluate changes made to a lagoon system. Start by measuring effluent $CBOD_5$, BOD_5, ammonia, nitrate, and DO at the effluent of all cells. When changes to the treatment system are made, judge performance based on improvements in intra-pond BOD_5, $CBOD_5$, TSS, ammonia, nitrate, and dissolved oxygen test results.

<u>Operational Notes:</u>

To evaluate and understand the effects of the changes that are made to the Breckenridge Minnesota wastewater lagoon system, intra-pond BOD_5, $CBOD_5$, temperature, ammonia, nitrate, phosphorous, DO, and pH must be routinely be made and recorded. These tests will enable the operators to make sound decisions when making changes to the system and monitor those changes for success. It will also help the operators to decide from which treatment cell to discharge

Intra-pond testing will help operations staff focus on specific areas where problems (opportunities for optimization) occur. Pinpointing where, when, and why a problem occurs saves time and money and simplifies lagoon optimization for TSS and $CBOD_5$ removal and pH control.

More than any other process control test, Cell # 1 effluent BOD_5 removal efficiency, and ammonia removal efficiency through each cell of the system will tell operations personnel when the influent loading is becoming a problem or if changes have taken effect. Determining removal efficiency requires pulling a BOD_5 sample from the Effluent of Cell # 1 while an influent BOD_5 sample is drawn and tested. Compare the two results. Cell # 1 removal efficiency should be at least eighty (80) percent. Operations staff should strive to keep Cell # 1 effluent BOD to less than 30 mg/l to ensure good ammonia removal from the other treatment Cells in the system. This does not happen until Cell # 3 at the Breckenridge lagoon system which is concerning.

Section 3 – Recommendations - Continued

BOD_5 and $CBOD_5$ should also be measured from the effluents of Cells # 1-5. $BOD_5 - CBOD_5 = NBOD_5$. $NBOD_5$ is the relative number of nitrifying bacteria in a system and denotes nitrification is or has the potential of occurring.

As much as possible, treatment should be “pushed back” to Cell # 1. Pushing BOD removal back to Cell # 1 is accomplished by adding sufficient DO to ensure DO is above two (2) mg/l at all times of the day and night, desludging and stopping short-circuiting. Higher treatment levels in Cell # 1 will allow for better ammonia, nitrate, and phosphorous removal in subsequent cells. Cells 2-4 should be for the conversion of ammonia to nitrate to nitrogen gas and settling dead bacteria and algae cells clarifying the water. This objective is more easily accomplished by getting the most productivity out of Cell # 1 as possible. Cell # 5 should be for killing pathogens by high pH, UVB, and high dissolved oxygen.

The Breckenridge lagoon system produced good numbers at the time of field testing and sampling and is compliant with its permit limits at this time.

Monitor water quality trends over time.

Figure 3. Operators receiving training in field testing at Breckenridge

Field Testing Data Analysis

Dissolved Oxygen Concentrations

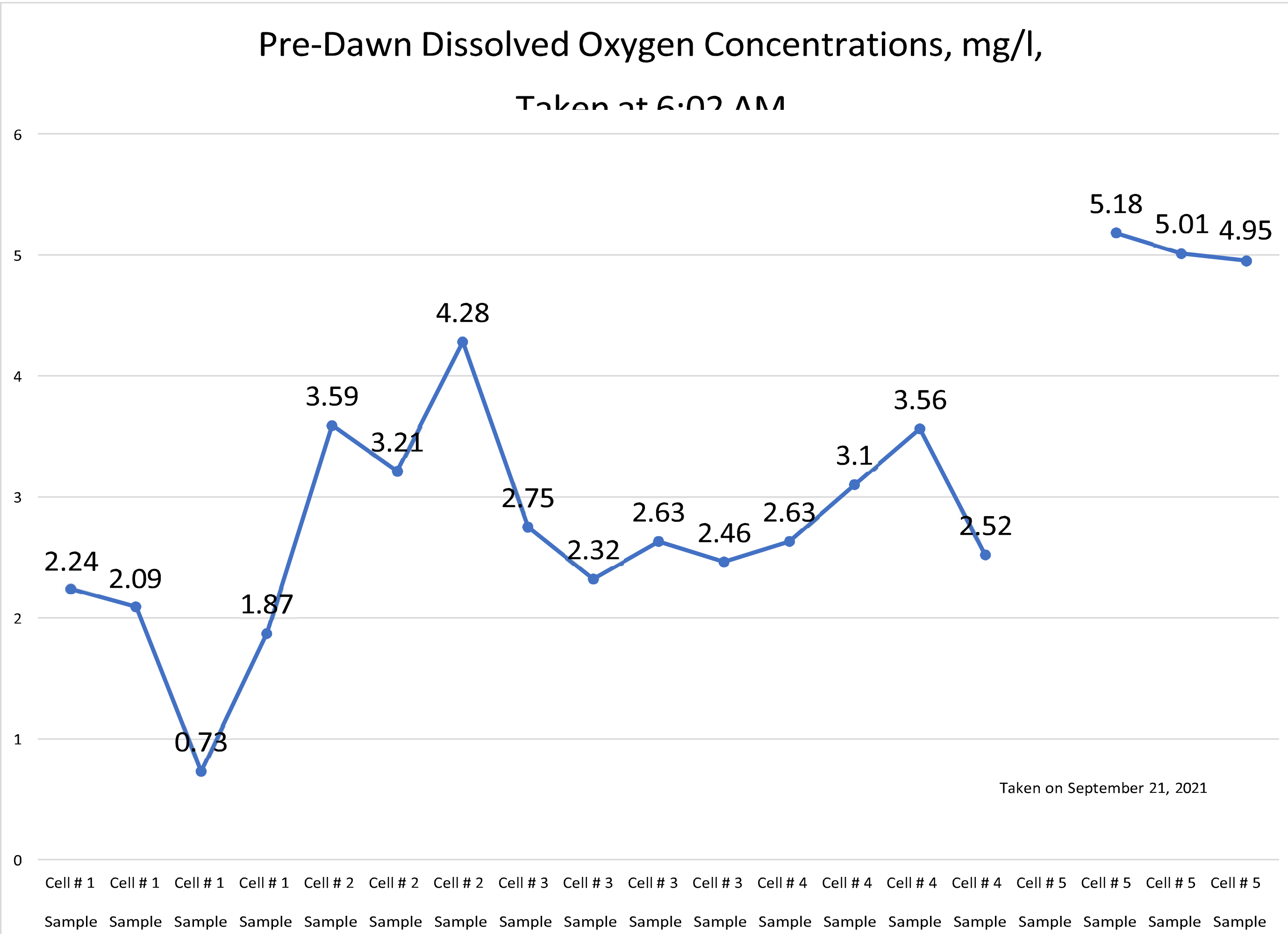


Figure 6. Predawn and Afternoon Dissolved Oxygen Concentrations.

Always keep dissolved oxygen concentrations above two (2) mg/l for greater $CBOD_5$, ammonia removal, odor control, and optimal performance.

There are two loading sources for the Breckenridge wastewater lagoon system, 1) the loading coming in daily and 2) the sludge blanket. Nutrients are stored in the bodies of dead bacteria, algae, and protozoa that make up the sludge blanket. This sludge feeds nutrients and soluble BOD back into the water column, putting a strain on the system. This loading manifests itself in low dissolved oxygen concentrations and increasing effluent TSS, $CBOD_5$, and ever-increasing pH.

Poor BOD_5 and $CBOD_5$ removal in Cell # 1 is more than likely due to the current shallow conditions as a result of the drought being experienced in Minnesota. It would be wise to retest each treatment cell for TSS, BOD_5, and $CBOD_5$ when water levels return to normal operating depths. If feedback is observed after retesting, desludge the treatment cell when effluent water quality from that cell approaches permit limits.

Section 4 – Field Data Analysis

Dissolved Oxygen Profile Taken by Boat from the Middle of Cell # 1

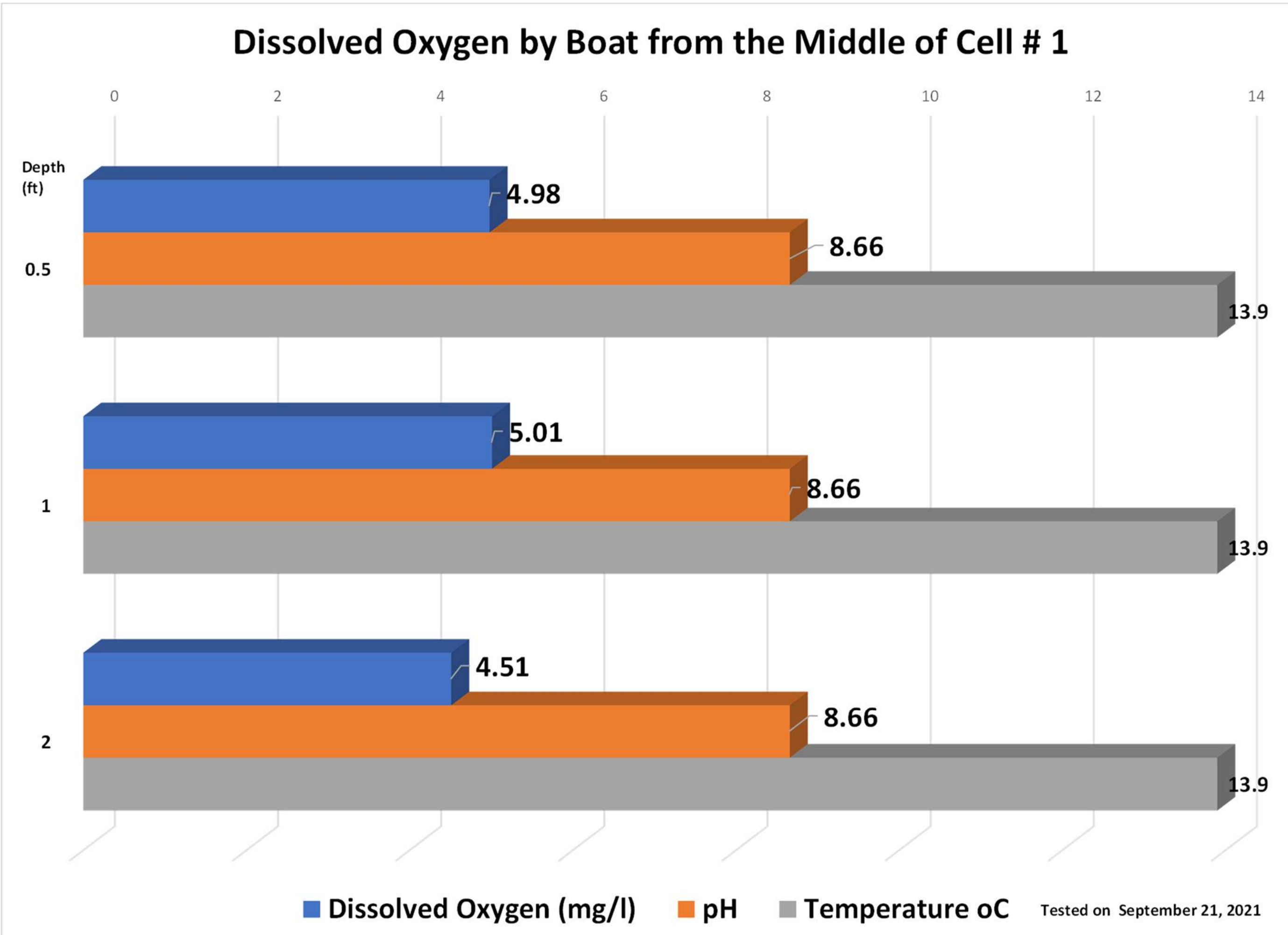


Figure 7. Cell # 1 Dissolved Oxygen Profile

Section 4 – Field Data Analysis

RMB Laboratories Intra- Pond BOD_5 Test Results

On Tuesday, September 21, 2021, samples were delivered to RMB Labs for intra-pond BOD_5 analysis. Below are the results.

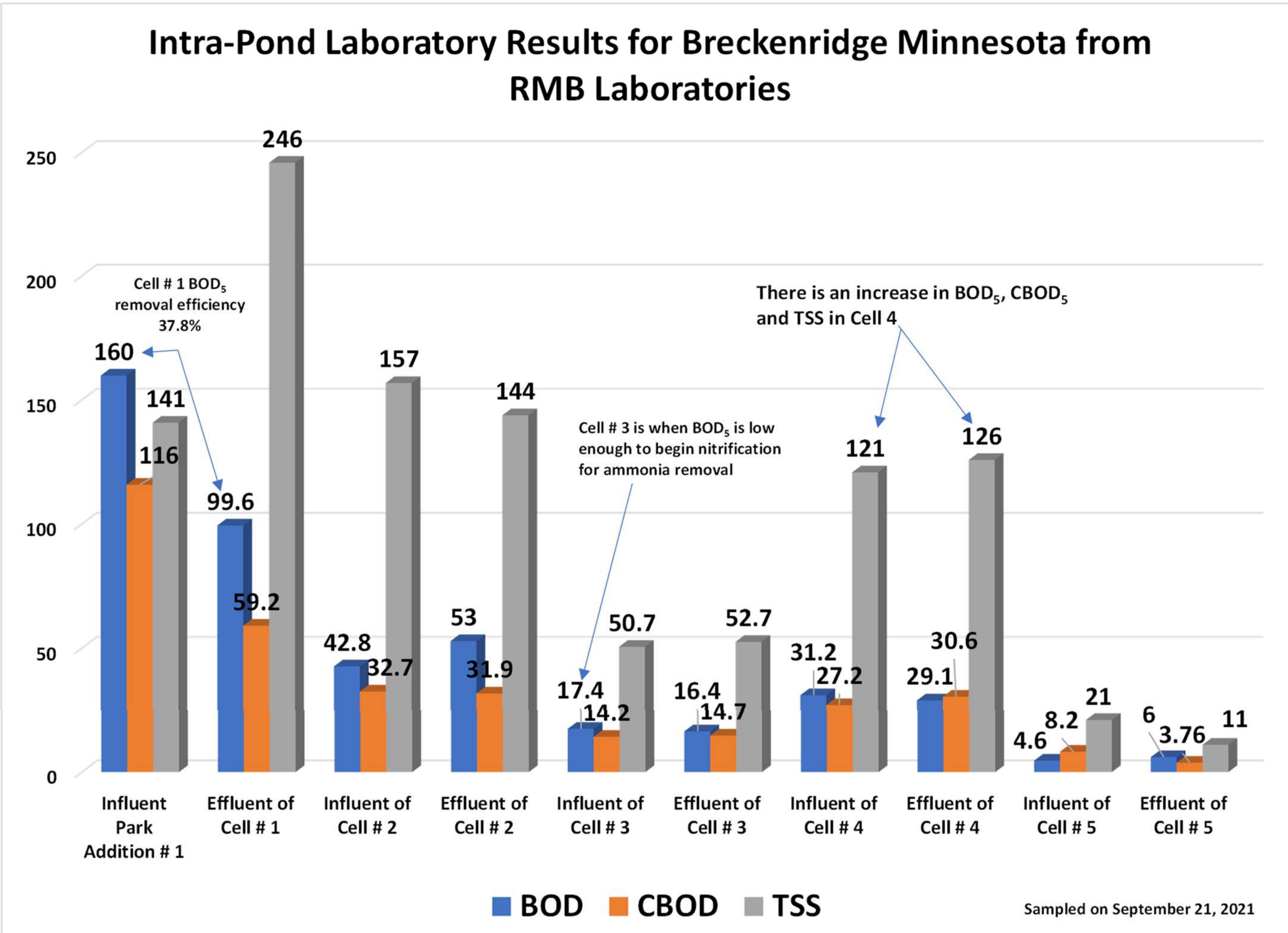


Figure 8. Intra-pond BOD_5, TSS, Results from RMB Labs

The Breckenridge lagoon system must wait until Cell # 5 to be $CBOD_5$ and TSS compliant. Cell # 5 should be settling dead algae cells and killing pathogens through UVB, high pH, and dissolved oxygen, not removing $CBOD_5$ or TSS.

Intra-pond BOD_5, $CBOD_5$, and TSS should be performed again when water levels return to normal.

An increase in $CBOD_5$ and TSS in Cell # 4 is not normal.

Benthal feedback is where the sludge feeds BOD_5, TSS, and algae growth by releasing nutrients once tied up in the cells of dead algae and bacteria that make up the sludge blanket. Algae is the number one cause of BOD_5 violations in the US because algae consume oxygen for five (5) days under dark conditions in the BOD_5 test bottle and incubator. When the lights are off algae, switch to oxygen consumption. That is why the most meaningful Dissolved Oxygen test is performed during the morning before sunlight hits the pond system. Benthal feedback caused by accumulated sludge is why $CBOD_5$ and TSS double in Cell # 4.

Section 4 – Field Data Analysis

Field Nutrient Testing

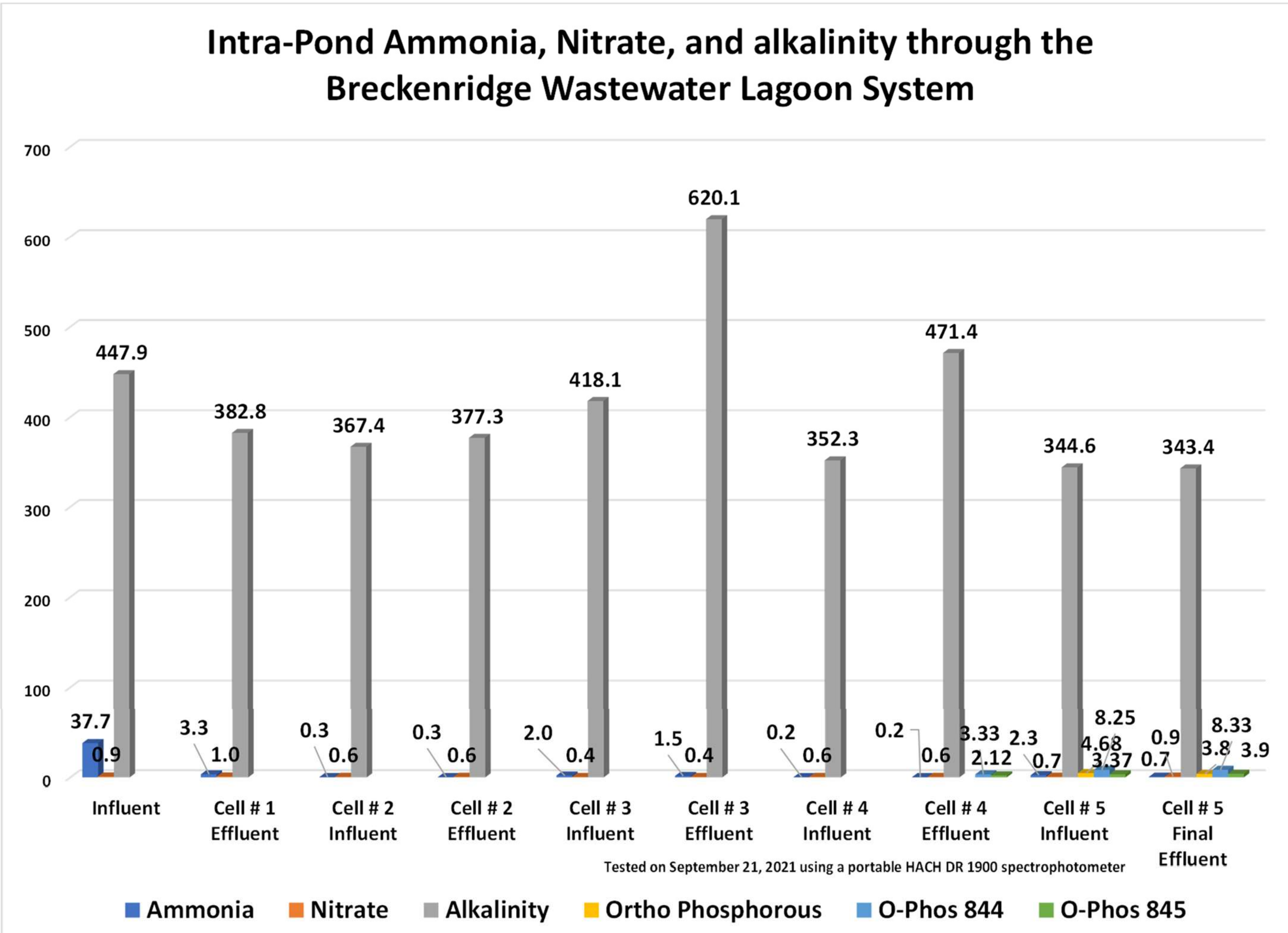


Figure 9. Intra-Pond Ammonia, Nitrate, Alkalinity, and Ortho-Phosphorous Results from Field Measurements

Ammonia removal is excellent. The primary ammonia removal pathway appears to be nitrification, then through assimilation, and then by volatilization by high pH.

$BOD_5 – CBOD_5 = NBOD_5$. $NBOD_5$ is the relative number of nitrifying bacteria in a system and denotes nitrification is or has the potential of occurring.

In the Breckenridge lagoon system, NBOD is 40.4 mg/l in Cell # 1, 21.1 mg/l in Cell # 2, and 1.7 in Cell # 3. When $CBOD_5$ and BOD_5 are the same or close, it means that most of the ammonia has been converted or consumed, leaving the NBOD close to zero (0). When nitrifying bacteria (NBOD) and ammonia get into the BOD_5 test bottle, they inflate the results of the $CBOD_5$ test resulting in permit violations.

Section 4 – Field Data Analysis

Sludge Accumulation

Breckenridge Minnesota						
Sludge Blanket Volume and Retention Time Summary						
Item	Units	Cell # 1	Cell # 2	Cell # 3	Cell # 4	Totals
Bottom Length	feet	1902	572	582	572	
Bottom Width	feet	1837	567	567	562	
Side Slopes	1 to	3	3	3	3	
Average Sludge Depth	feet	1.1	1.08	1.06	0.86	
As-Built Bottom Elevation	feet	0.00	0.00	0.00	0.00	
As-Built Top-of-Bank Elevation	feet	7.00	7.00	7.00	7.00	
Bottom Area	sq ft	3,493,974	324,324	329,994	321,464	
Top of Sludge Length	feet	1908.6	578.48	588.36	577.16	
Top of Sludge Width	feet	1843.6	573.48	573.36	567.16	
Top of Sludge Area	sq ft	3,518,695	331,747	337,342	327,342	
Sludge Volume	cu ft	3,856,968	354,278	353,688	278,987	4,564,934
Sludge Volume	gallons	28,850,120	2,650,001	2,645,587	2,086,820	34,145,708
Embankment Height	feet	7.00	7.00	7.00	7.00	
Freeboard Required	feet	2	2	2	2	
Useable Lagoon Depth / Remaining Water Cap after Sludge	feet	1.81	1.92	1.94	2.14	
Top of Water Max Length	feet	1920	590	600	590	
Top of Water Max Width	feet	1855	585	585	580	
Top of Water Max Area	sq ft	3,561,600	345,150	351,000	342,200	
Lagoon Volume	cu ft	6,385,294	642,695	660,564	710,120	7,688,554
Usable Lagoon Volume at Current Operating Depths with Sludge	gallons	47,762,003	4,807,359	4,941,020	5,311,701	57,510,382
Ave Daily Influent Flow, Mo Ave Over 4 years : 0.329 MGD (DMR)						
Retention Time Based on Sludge Volume, Estimated Cell 2 - 4 Operating Depths, and Remaining Water Cap Capacity	days	145.17	14.61	15.02	16.14	174.80
Notes & Cautions:						
Elevations are estimates from engineering plans are used.						
Dimensions are from engineering plans						
Treatment Cell bottoms were uneven.						
Rounded corners exist, square corners are used in the calculations above						
Averages of water depths and average sludge blanket thickness are used						
Slopes are assumed at 3:1 from engineering plan set						
Flow is a five (5) year average influent from DEQ Records.						
Water Depth in Cells 2-4 was not measured but assumed to be three (3) feet						

Figure 10. Sludge Blanket Volume and Retention Time Calculations.

Section 4 – Field Data Analysis

This report relies on a sludge blanket profile performed by Interstate Engineering, Wahpeton, North Dakota on August 2018. The charts presented in this report are based on Interstate's sludge judging numbers.

On September 21, 2021, H&S and Breckenridge attempted to sludge profile the lagoons. Problems with the boat motor prevented a complete profile.

The survey performed by H&S and Breckenridge around the periphery of Cell # 1 showed an average sludge blanket thickness of 1.45 feet. Using H&S's method of sludge judging, a survey level rod was used to measure the water depth at ten (10) sample points in the lagoon. At the same time, an infrared sludge level detector set at medium was used to detect the top of the sludge blanket. Excel calculated the difference between the top of the water and the top of the sludge, effectively measuring sludge blanket thickness.

Aside from occupying valuable capacity and lowering a treatment cell's retention time, sludge releases nutrients and soluble BOD back into the water column. These nutrients feed TSS production through algae growth. Because they consume oxygen under the dark conditions of the BOD_5 test, algae can result in high BOD_5. The release of nutrients from sludge feeds algae growth resulting in TSS permit violations.

Once sludge reaches about eighteen (18) inches in thickness, it is time to consider removal to prevent nutrient feedback causing problems with increases in algae growth leading to TSS problems.

Sludge removal options include dredging, pressing or centrifuging, and hauling off-site, as well as removing in situ with chemical oxidizing agents. Each method has its place. Sludge can also be pumped out and applied to a Geo-Tube or drying bed to dry on-site for two (2) years. Drying on-site allows for the removal of the water, reducing tipping fees and hauling costs. When dredging or drying, and scraping, the treatment cell must typically be taken offline.

Dredging mixes a treatment cell releasing ammonia, nitrates, phosphate, and CO_2 to stimulate algae and bacteria growth. The filtrate from a belt press will concentrate nutrients as it squeezes sludge, creating a stream of nutrient-rich water that will load the plant. This nutrient-rich filtrate stream will, in most cases, cause a crash in DO and create odors. Be aware of the centrate or filtrate coming off the centrifuge, press, or weepage from a Geo-tube or runoff from a drying bed. Add air to the remaining working treatment cells when desludging. Keeping air above two (2) mg/l will keep odors and nutrient loading to a minimum.

If time permitted, mixing the sludge blanket and adding agricultural stubble breakdown chemistries can remove several feet of sludge over time. Mixing and chemical agents will not remove sand grit or gravel and leave dead bacteria bodies (Humus). The disadvantage of treating in place by mixing and adding is that you run the risk of freeing ammonia, nitrate, phosphate, CO_2, and organic acids to feed an algae bloom. Consult an expert before mixing a treatment cell. There are proven chemical additives from the agricultural industry that can accelerate sludge removal on-site associated with mixing.

Section 4 – Field Data Analysis

Aeration and Dissolved Oxygen

There are seven (7) indicators that the dissolved oxygen levels in the Breckenridge Minnesota Pond system are too low:

1) Poor BOD_5 removal efficiency
2) Low ammonia removal efficiency
3) Odors
4) Popping sludge in the treatment Cells
5) *Daphnia* turned red in the treatment Cells
6) Low DO measurements both day **and** night. The best, most meaningful time to measure DO is before sunrise before algae have had the chance to produce dissolved oxygen
7) Increasing trends in effluent BOD_5 after all the Cells have been desludged

Dissolved oxygen measurements taken at the surface may not tell the whole story. While the surface water may appear to have sufficient DO, it may be anoxic just below the surface, beginning two to three feet below the surface. Measuring Dissolved Oxygen by boat in the middle of a treatment cell from the surface to the bottom at the sludge water interface is the best way to perform a DO profile. This type of DO profile is also best performed at or before sunrise.

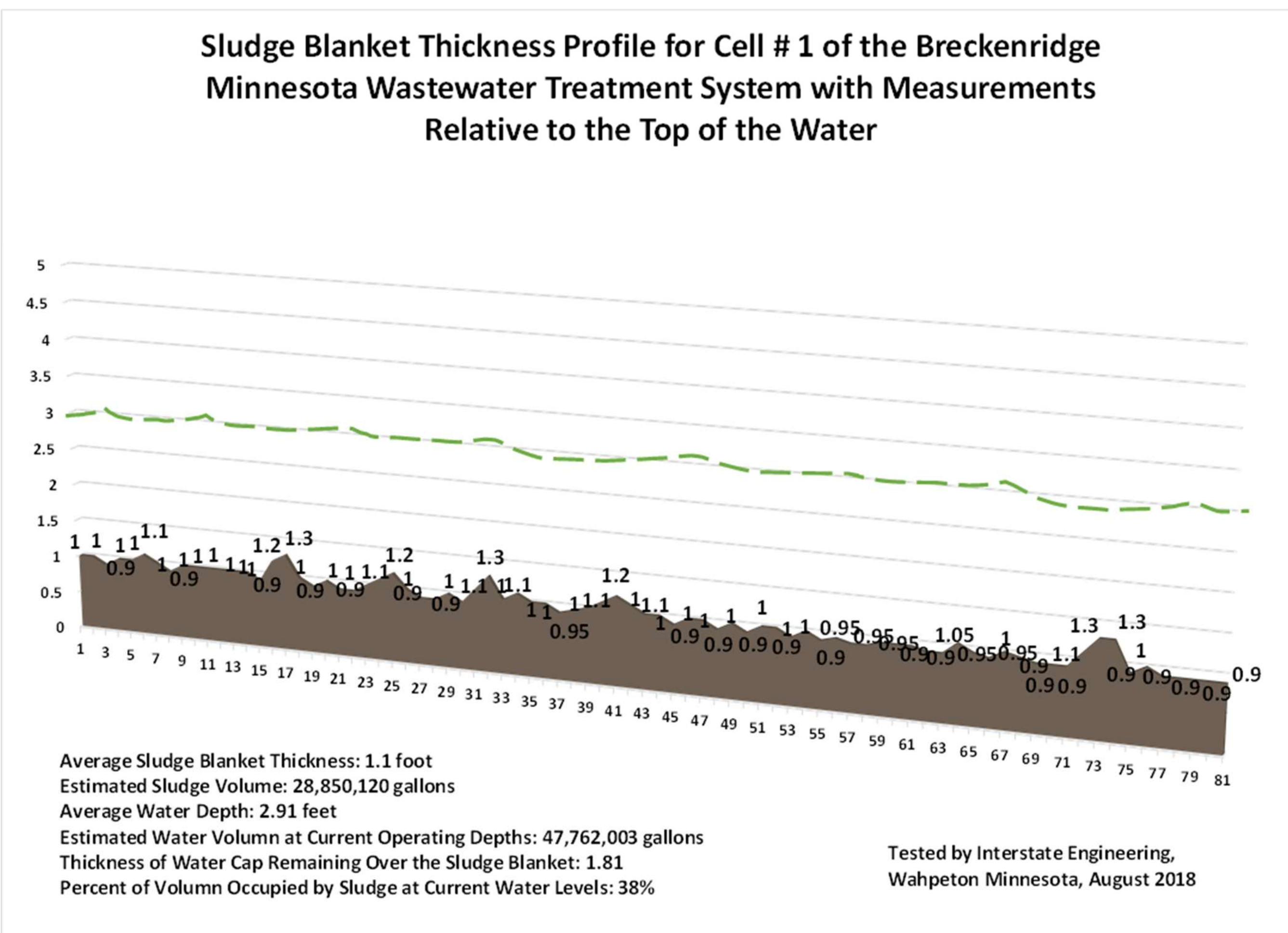
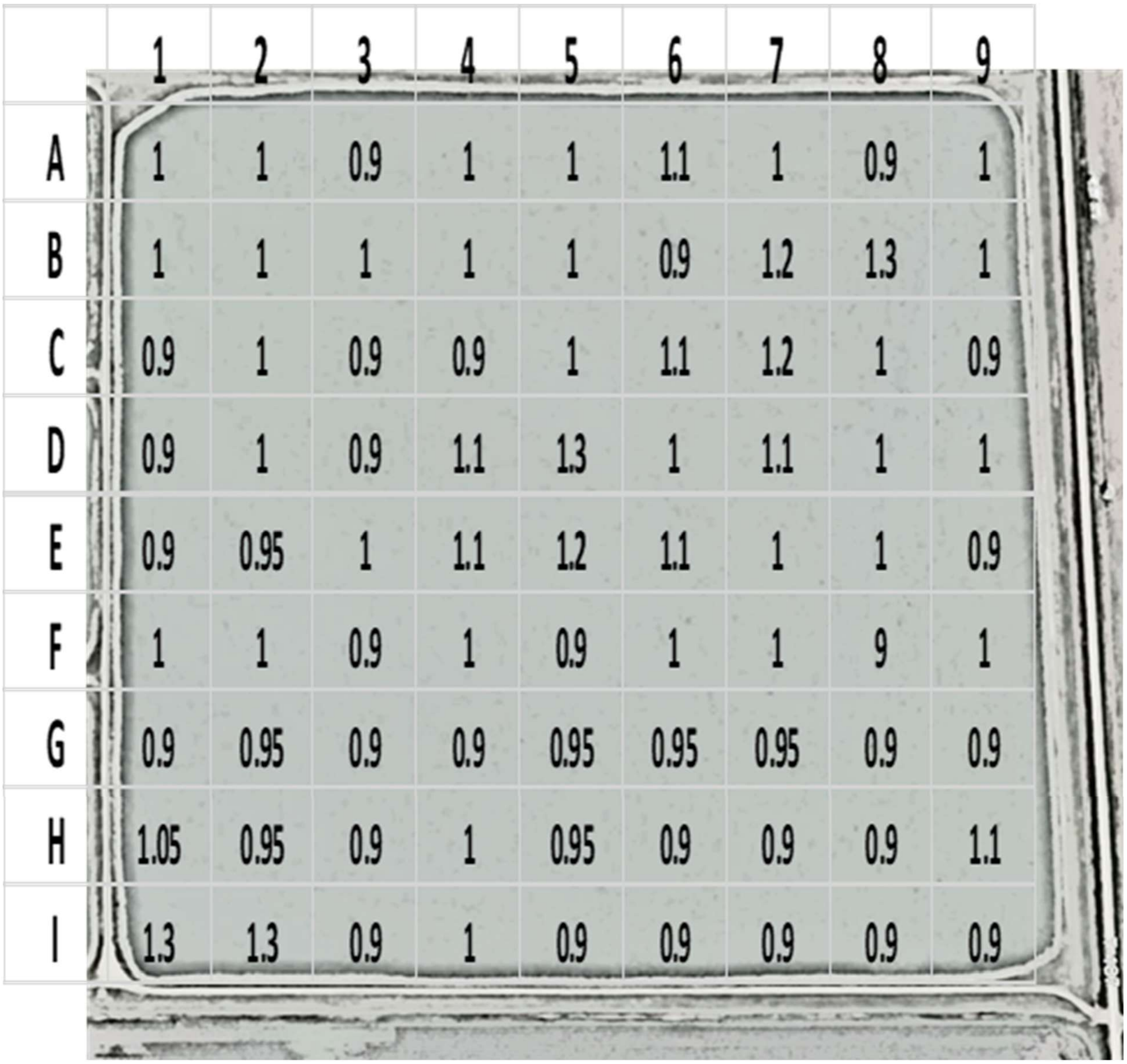


Figure 4. Sludge Blanket Thickness Relative to the Top of the Water Showing How Thin the Water Cap is Over the Sludge Blanket During Drought Conditions

Section 4 – Field Data Analysis-Continued



	1	2	3	4	5	6	7	8	9
A	1	1	0.9	1	1	1.1	1	0.9	1
B	1	1	1	1	1	0.9	1.2	1.3	1
C	0.9	1	0.9	0.9	1	1.1	1.2	1	0.9
D	0.9	1	0.9	1.1	1.3	1	1.1	1	1
E	0.9	0.95	1	1.1	1.2	1.1	1	1	0.9
F	1	1	0.9	1	0.9	1	1	9	1
G	0.9	0.95	0.9	0.9	0.95	0.95	0.95	0.9	0.9
H	1.05	0.95	0.9	1	0.95	0.9	0.9	0.9	1.1
I	1.3	1.3	0.9	1	0.9	0.9	0.9	0.9	0.9

Figure 12. Cell # 1 Sludge Blanket Locations

Section 4 – Field Data Analysis Cont-

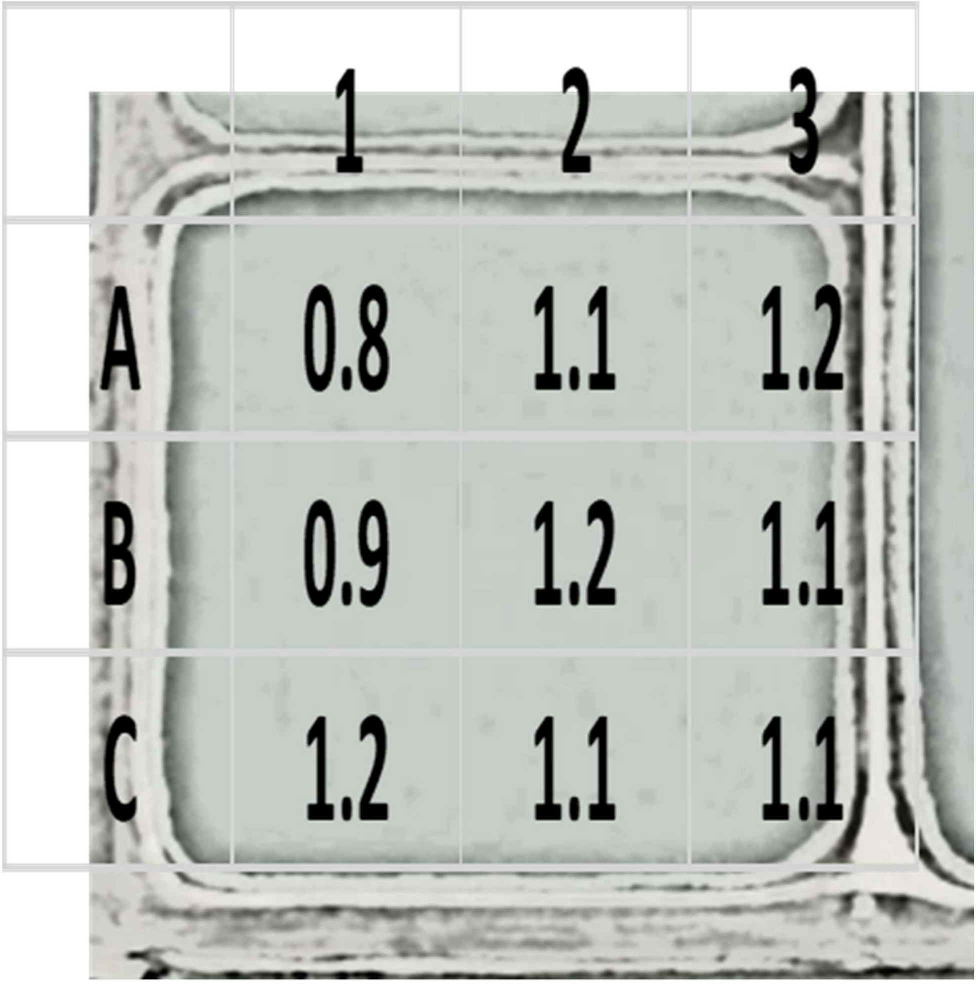


Figure 13. Cell # 2 Sludge Blanket Thickness Locations

Cell # 3 has accumulated 1.06 feet of sludge and Cell # 4, 0.86 feet according to Interstate Engineering in August of 2018. Sludge has a powerful impact on the effluent water quality of lagoon systems and should not be allowed to accumulate past eighteen (18) inches. Because it is so expensive to remove, the City of Breckenridge should begin to save for the inevitability of desludging.

Lagoons fail for two main reasons; 1) Poor hydraulic design (short-circuiting) and 2) Sludge accumulation.

Short-circuiting is the worst thing that can happen to a lagoon system short of someone dumping toxic waste in the system. Sludge is the second worst thing that can affect effluent quality. Sludge stores the nutrients once assimilated and then releases them back to the water column as the dead algae and bacteria cells lyse.

Algae growth cause CBOD problems by consuming oxygen, not making it, when the lights are off. In the lagoon cells or for five (5) days, a sample sits in a BOD_5 test bottle under dark conditions, and algae consume oxygen over those five (5) days inflating the $CBOD_5$ test result. Sludge feeds algae growth, and algae growth leads to TSS violations and $CBOD_5$ problems because of this.

There is a mandate in the New England States to remove sludge after it reaches eighteen (18) inches in thickness because of the problems sludge creates.

Section 5 – DMR Data Analysis

The trend in Average Monthly BOD in kg/day is slowly increasing.   So also, is the Monthly concentration.

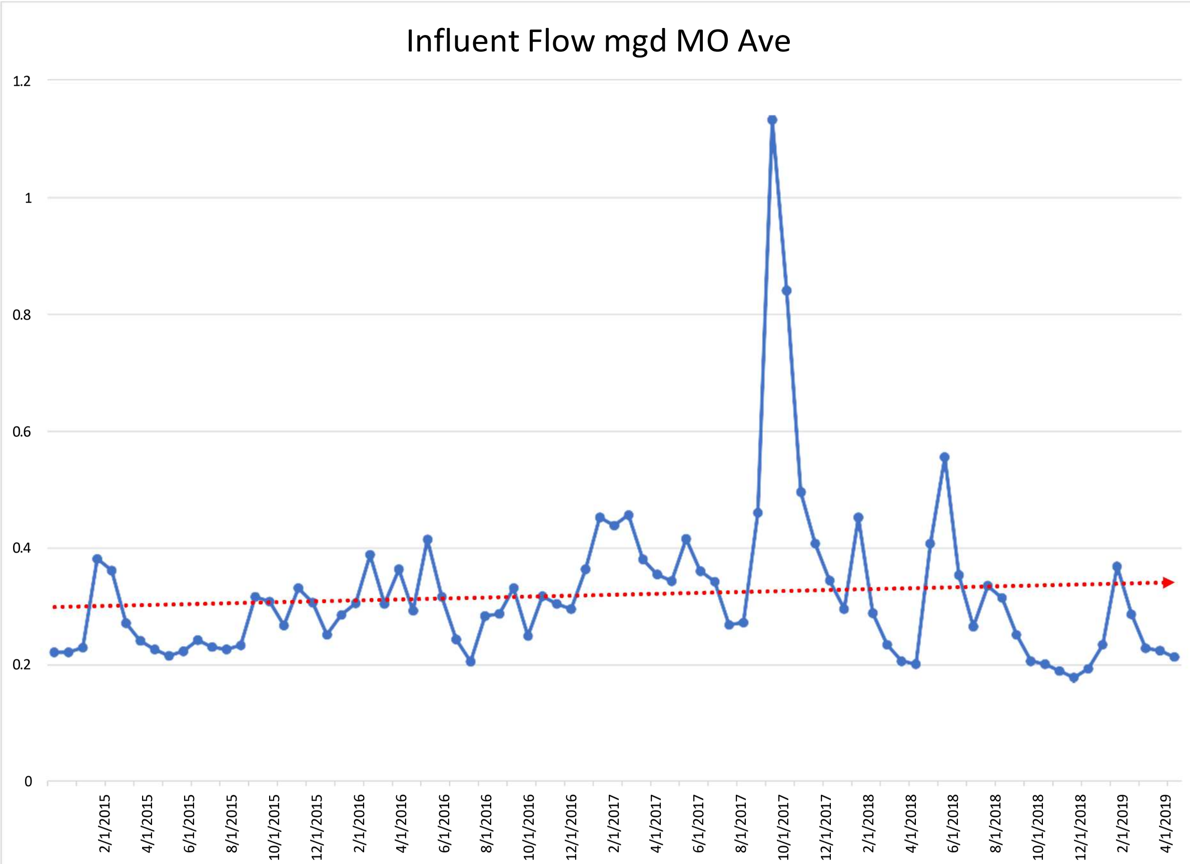


Figure 15. The Trend in Influent Flow is Increasing

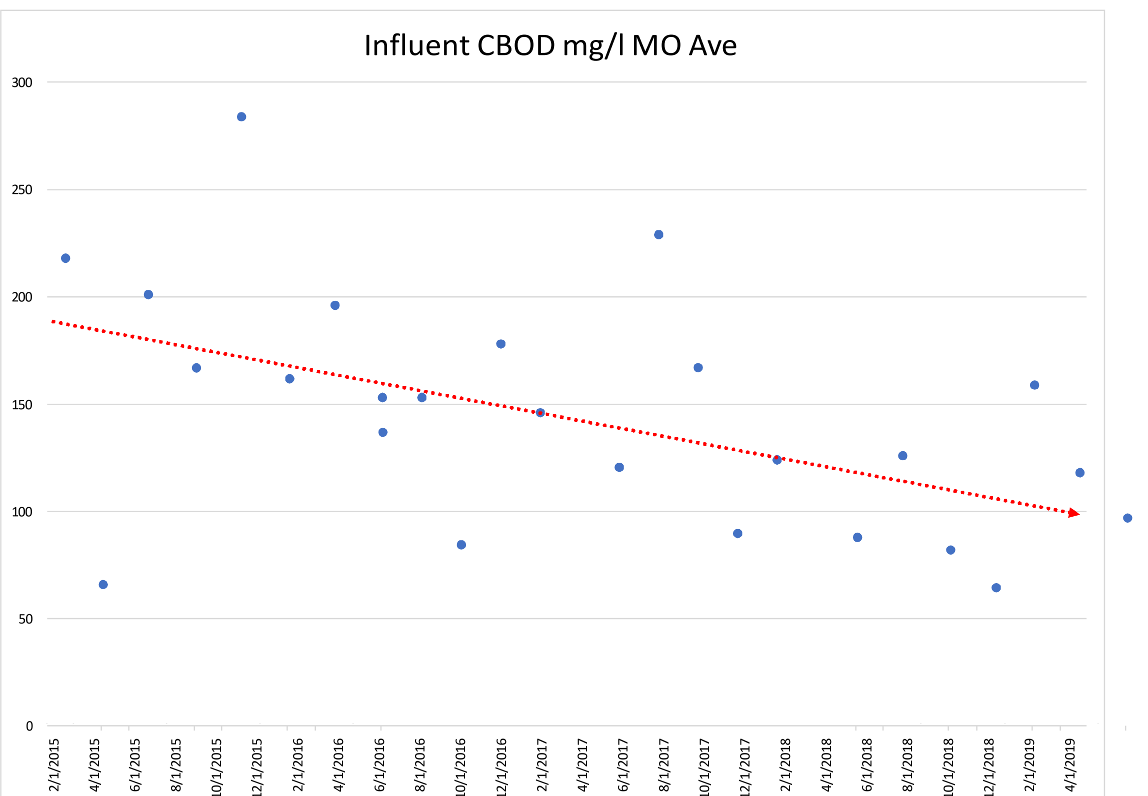


Figure 5. The Trend in Monthly Average Influent CBOD in Decreasing

Section 4 – DMR Data Analysis Cont-

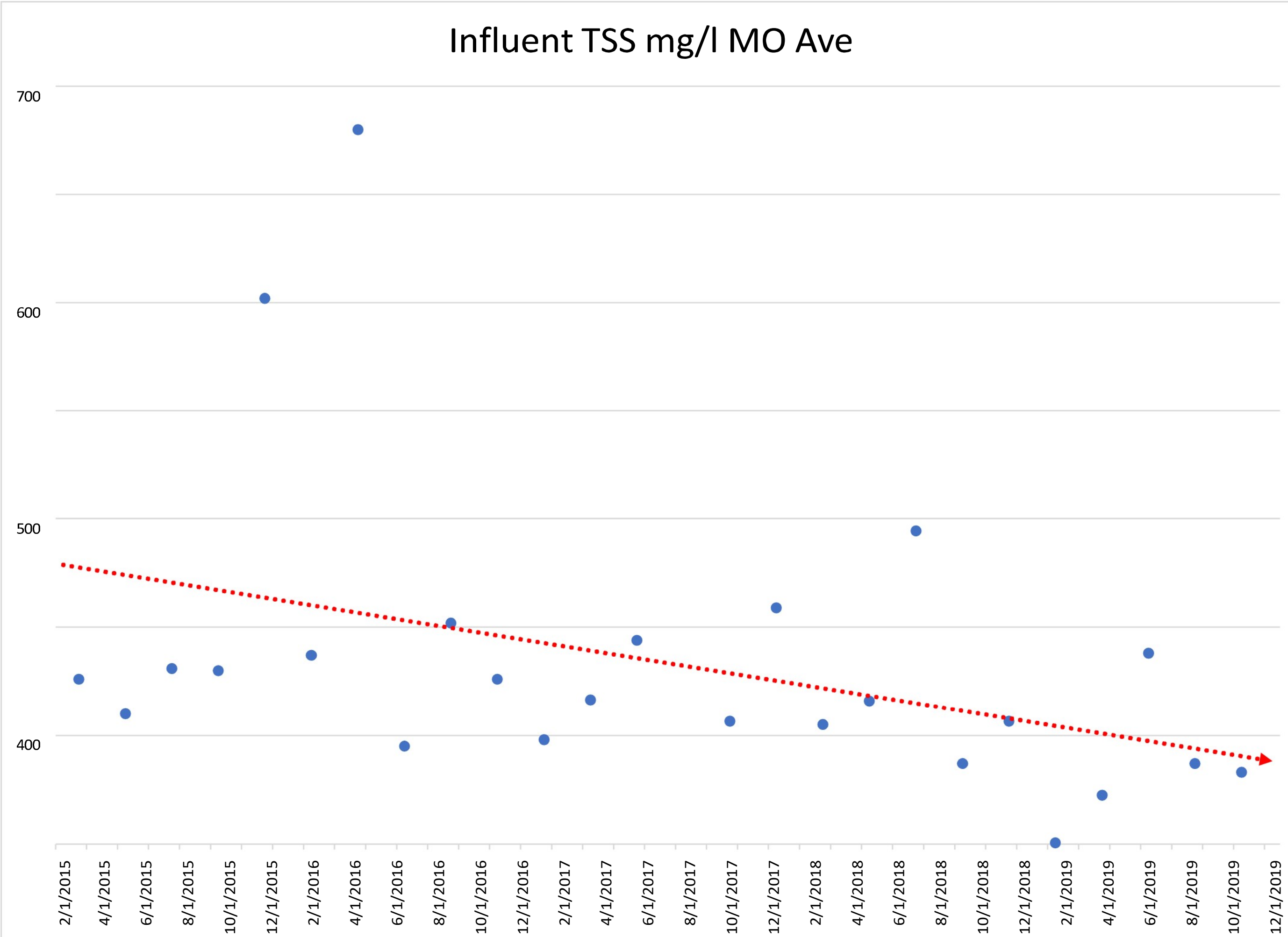


Figure 17. Monthly Average Effluent TSS is Trending Down

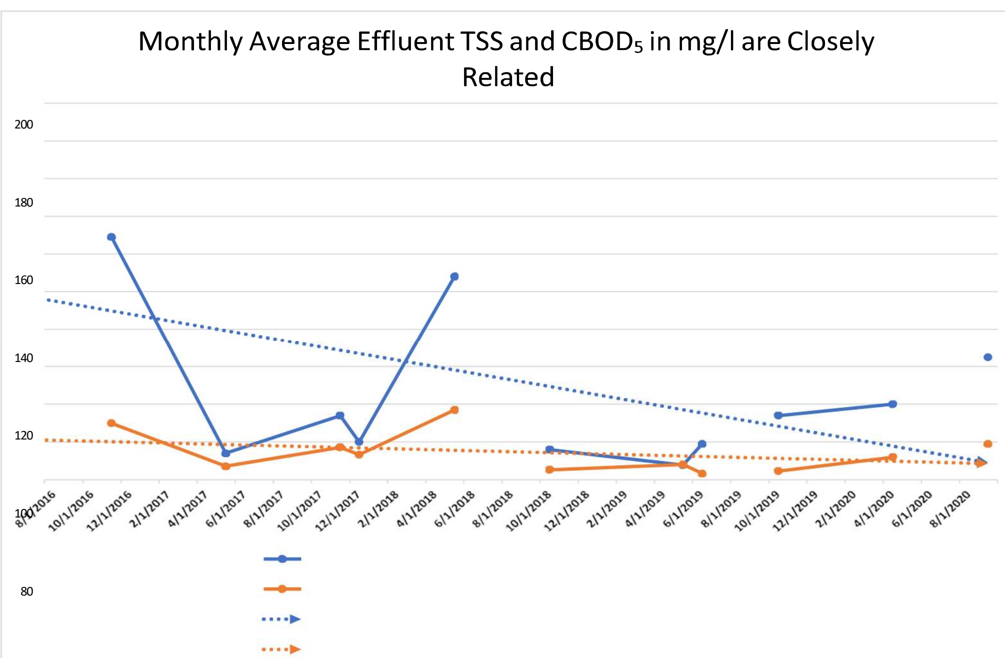


Figure 6 Effluent TSS and CBOD are so Closely Related that One can be Used to Predict Another.

Section 4 – DMR Data Analysis Cont-

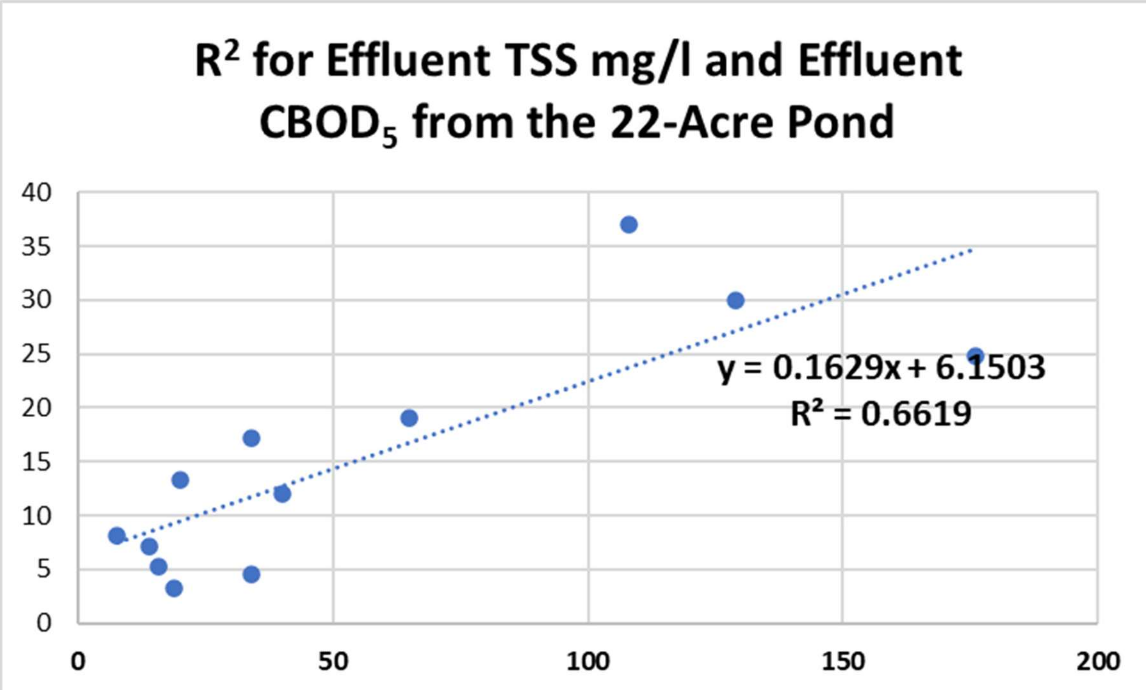


Figure 18. The Closer Two Variables Fit on a Line Together, the Closer the Relationship Between the Two

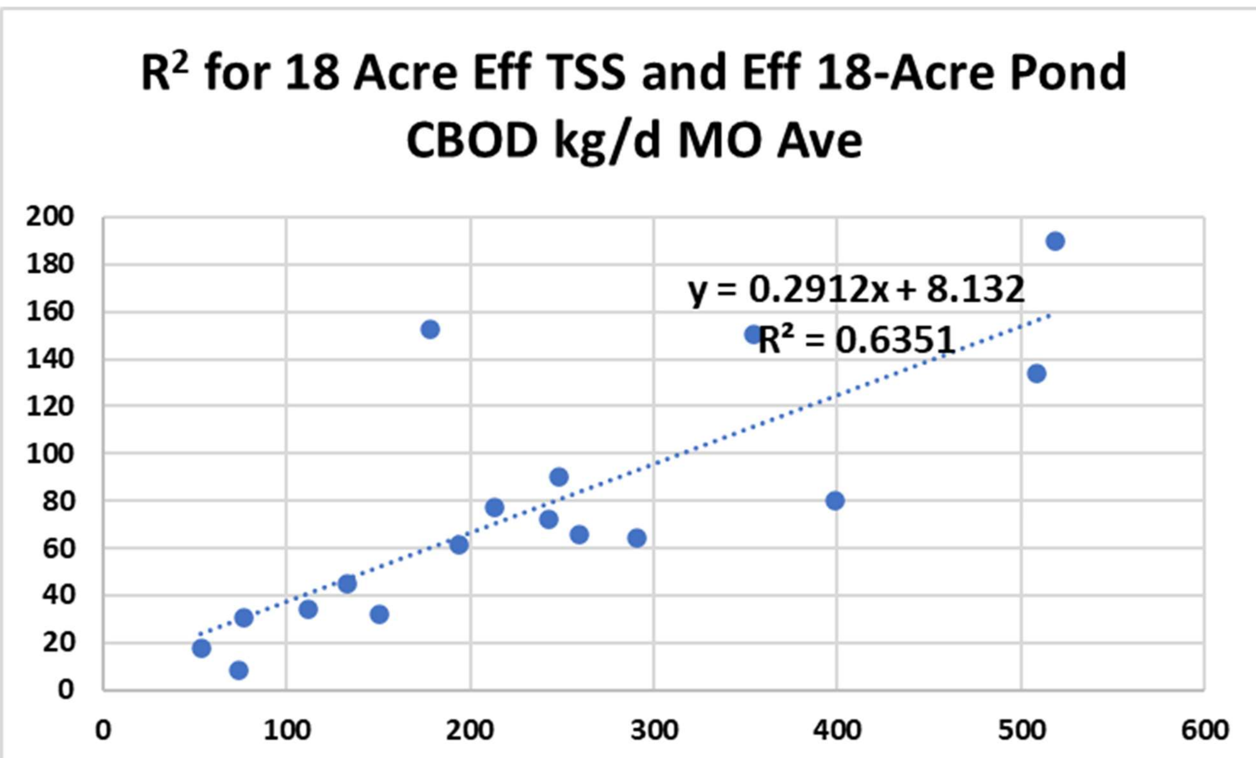
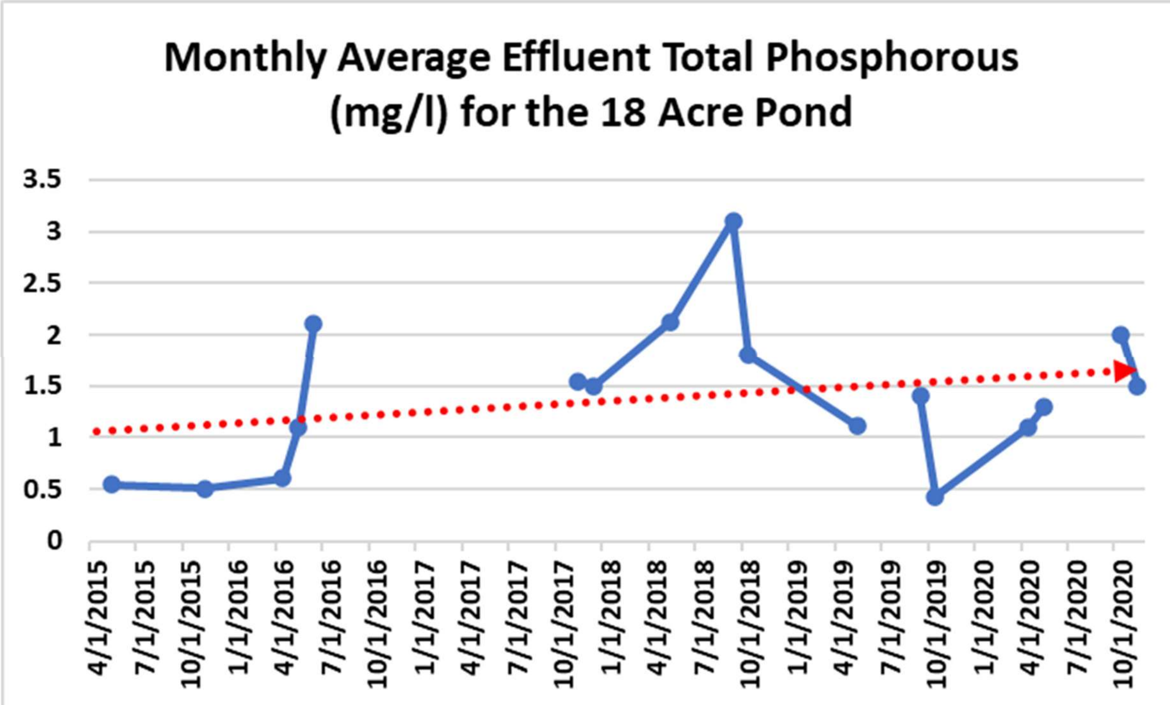


Figure 19. R^2 for Effluent TSS and Effluent CBOD for the 22-Acre Pond

Statistically, R^2 shows the strength of the relationship between two (2) variables. The closer these numbers are to the number one (1), the closer the relationship. In other words, one variable can be used to predict another variable the closer the R^2 number is to the number one (1). In Breckenridge's case, if TSS can be lowered, $CBOD_5$ will be lower correspondingly.

Over the entire dataset, TSS and $CBOD_5$ are the most related statistically.

Section 4 – DMR Data Analysis Cont-



Figures 22 Effluent Phosphorous in mg/l from the 18-Acre Pond is Trending Up

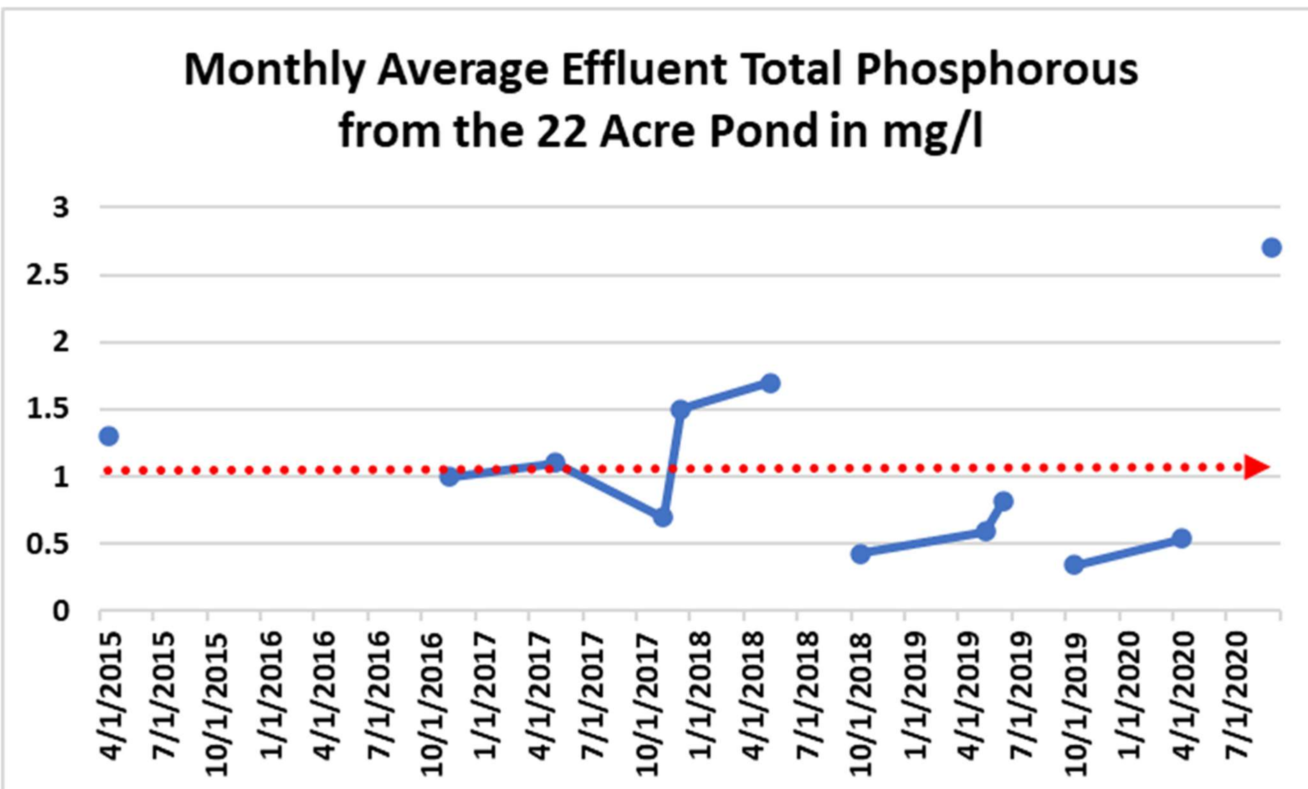


Figure 21. Effluent Total Phosphorous from the 22-Acre Pond Trending Slightly Up

Section 4 – DMR Data Analysis Cont-

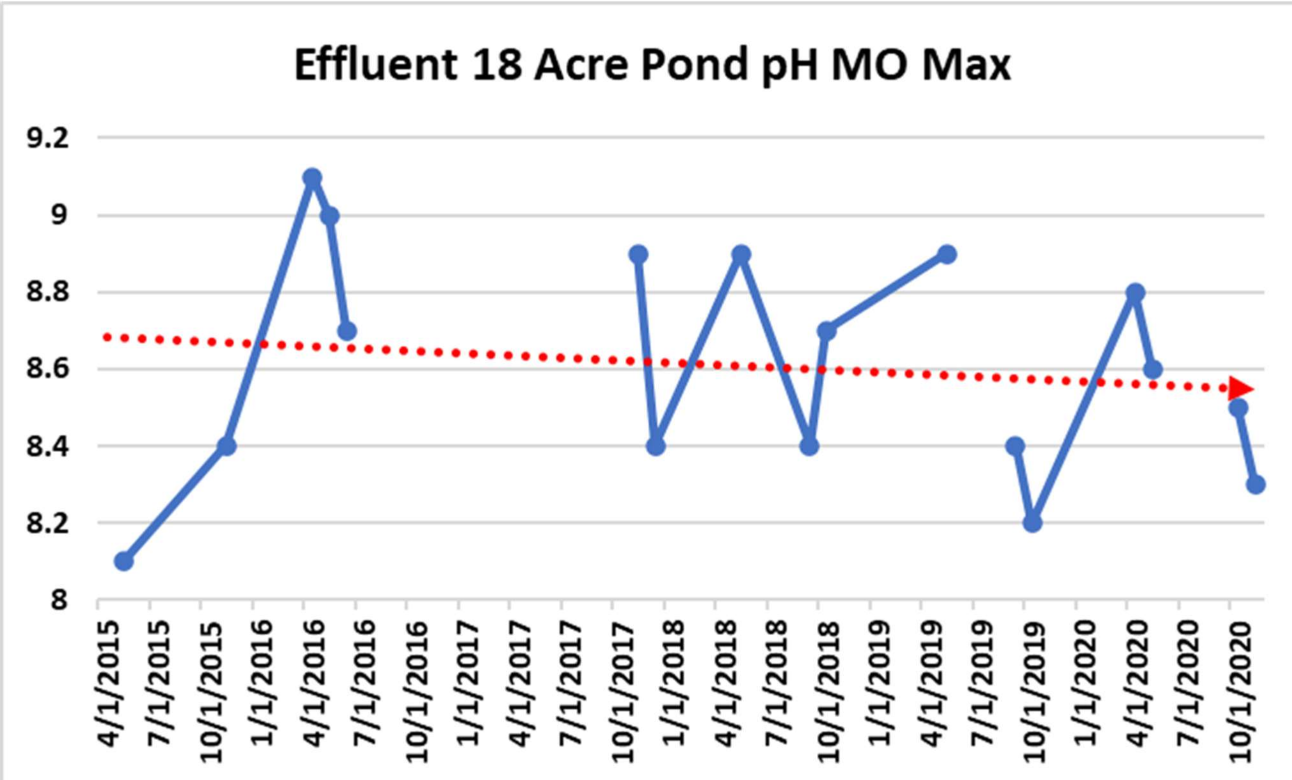


Figure 7. Effluent pH Max from the 18-Acre Pond

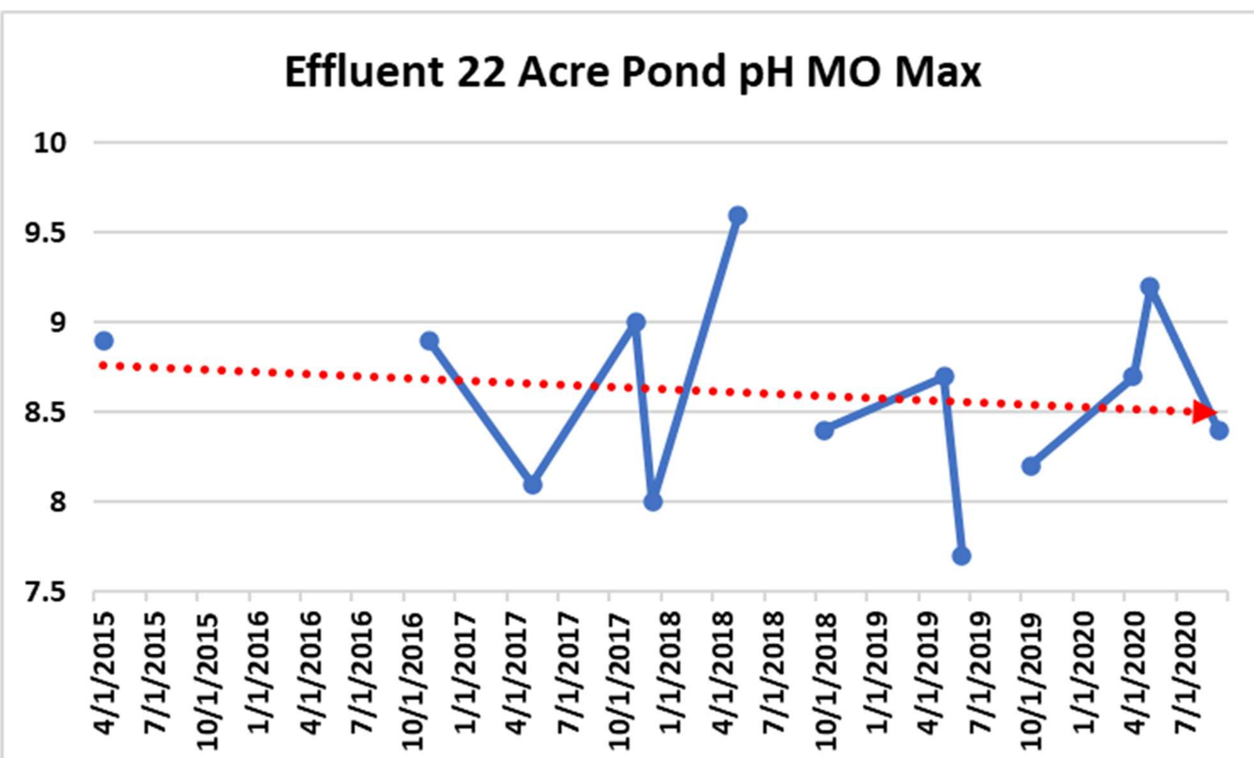


Figure 8. Effluent pH Max from the 22-Acre Pond

Section 5 – Summary

Breckenridge Minnesota wastewater pond system is healthy and typically meets permit limits. When it violates its limits, it does so because of the influence of algae on pH and TSS. The key to meeting permit limitations in the long term is to discharge as few algae cells as possible, and the cheapest and easiest method to do this is to remove water from the treatment cell having the best water quality. Determining which cell has the best water quality will require intra-pond testing to determine which of the five (5) treatment cells meets treatment standards at the time of discharge. There are other TSS control strategies mentioned in this report. The Breckenridge lagoon system violates its permit limits every two years and will probably violate them in the future. Being proactive will help Breckenridge stay ahead of permit violations.

Section 6 – Action Items

The recommendations outlined in this report offer solutions for meeting permit limits in a long-term sustainable fashion.

Four (4) Action Items are recommended for the Breckenridge Minnesota wastewater lagoon system, and they are:

1) Plan to desludge Cell # 1 in the next three (3) years
2) Closely monitor the trends in water quality permit parameters between each treatment cell. When they get close to permit limits, it is time to desludge
3) Pull discharge water from at least four (4) feet below the surface of the water and one foot up off the bottom of the treatment cell, and one (1) foot past the toe of the dike if possible.
4) Quarterly perform intra-pond diagnostic BOD, TSS, and pH sampling between each treatment cell to see if sludge is affecting water quality. Determine why Cell # 4 water quality gets worse. Re-sludge judge Cell # 4 soon. Minnesota Rural Water may help with this. Ask.

Section 7 – Conclusions

CONCLUSIONS

The Breckenridge wastewater lagoon system is healthy and run by a competent crew doing a fine job keeping the system within permit limitations. The pond system is generally working well to deliver good water quality.

There is a ***where,*** **a** ***when,*** **and a** ***why*** to lagoon problem solving and optimization. Determining where treatment is not occurring is essential to optimizing Breckenridge, Minnesota's wastewater lagoon system, for continued sustainable permit compliance.

Please see Diagnostic BODs in the attachments and commit to routinely performing these kinds of tests.

Section 7 – Conclusions-Continued

Thank you for the opportunity to serve the good people of Breckenridge, Montana.

Steve Harris President
H&S Environmental, LLC

Attachments

1) Diagnostic BODs
2) Algae's Contribution to the BOD_5 Test Result
3) The Importance of Mixing Lagoon Sludge Blankets

References

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H&S Environmental, LLC.

- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization
- Training

2122 East Leland Circle Mesa, AZ 85213 1 (480) 244-8410

Date: October 27, 2021

Ted Priester
Executive Director
Red River Basin Commission
1120 28th Avenue N, Suite B
Fargo, North Dakota 58201

Re: Performance Evaluation of the Hillsboro North Dakota Wastewater Lagoon System

Ted,

Enclosed is the October 27, 2021 report for H&S Environmental's (H&S) performance evaluation of the Hillsboro North Dakota (Hillsboro) Wastewater Lagoon System.

The purpose of this report is to identify operational conditions and practices that should prevail to keep the effluent of the Hillsboro Wastewater Lagoon System within permit limits.

All facility data, sludge depth data, and other field data used in this report were compiled by Hillsboro and H&S Environmental, LLC (H&S).

The conclusions reached in this performance evaluation are based on five (5) primary data sources:

1) The results of intra-pond biological oxygen demand (BOD_5) testing by RMB Environmental Laboratories, Inc.
2) The analysis of four-point-eight (4.8) years of DMR data from the US EPA ECHO database
3) Field-testing of Ammonia, Nitrate, Alkalinity, Dissolved Oxygen, and pH results by the Hillsboro and H&S Environmental, LLC
4) Sludge judging results by Hillsboro and H&S Environmental, LLC
5) DEQ Permit # NDG 121903

Performance Evaluation of the Hillsboro North Dakota Wastewater Lagoon System

The City of Hillsboro, North Dakota wastewater facility is located at
47 25 30.35N, 97 02 59.29W

Permit Number NDG 121903

October 27, 2021

Prepared for

The International Red River Board

Project Title:
Supporting the IRRB's Nutrient Management Strategy Through Workshops and Technical Assistance in the Red River Basin

Prepared by
H&S Environmental, LLC
Steve Harris, President

This document was prepared under contract with the IRRB

Disclaimer

This document assumes basic wastewater operations knowledge, skills, understanding, and compliance with applicable federal and state permit limits.

Acknowledgments

This performance evaluation was prepared with assistance from Ted Priester, Executive Director, Red River Basin Commission

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Figure 1. The Hillsboro North Dakota, Facultative Wastewater Lagoon System

Executive Summary:

This report will focus on the results of field nutrient testing by H&S Environmental and Hillsboro, sludge judging by H&S and Hillsboro, laboratory analysis by RMB Laboratories, Inc, as well as 4.8 years of DMR data from the US EPA ECHO database for recommendations on optimizing the Hillsboro wastewater lagoon system.

Because of the lack of flow, field and laboratory samples were taken directly from each of the treatment cells except for the influent sample taken from the influent wet well. The data from these samples show that final effluent BOD_5 and TSS are compliant and within permit limits. Effluent Ammonia was 0.109 mg/l, Soluble BOD was three (3) mg/l, and Ortho Phosphorous was 2.94 mg/l. Dissolved oxygen before sunrise in Cell # 1 was over 10 mg/l, with dissolved oxygen in Cell # 1 rising to over twenty-two (22) mg/l during the afternoon. Effluent pH was non-compliant on the day of field testing, and at its highest point, pH measured 9.16 SI.

There are only seven (7) discharge events in the past four-point-eight (4.8) years. Because of the small number of data points, statistical analysis of the DMR data set will not be possible for the Hillsboro system. There have been three (3) permit violations since January 2016. All three (3) violations (TSS and pH) are related to algae growth.

The primary ammonia removal pathway appears to result from nitrification, but volatilization through high pH and assimilation by algae also remove ammonia. There is a two-hundred and fifty-nine (259) day retention time at Hillsboro, giving the water time to exhaust nutrients producing clean water.

If Hillsboro were required to discharge on the day of field testing and sampling, it would meet permit limits for BOD_5 and TSS but not pH.

Field testing of dissolved oxygen (DO) showed sufficient DO concentrations in all treatment cells for BOD_5, TSS, and Ammonia removal.

Ammonia and Ortho-Phosphorous showed progressive reduction through all three (3) cells of the treatment system.

No treatment cells require sludge removal at this time. Cell # 1 should be re-sludge judged in five (5) years to estimate sludge accumulation rate and to determine when sludge will reach eighteen (18) inches in thickness. Because of the volume and considerable expense, it is best to set aside money now for this expensive operation. Sludge should be removed when it reaches eighteen (18) inches in thickness or when effluent water quality approaches permit limits. Sludge has accumulated in Cell # 1 to an average of 0.75 feet, Cell # 2 to 0.83 feet, and Cell # 3 to 0.88 feet.

The Hillsboro wastewater lagoon system is performing well and producing good water quality. The system is healthy and is run by competent and caring operation staff.

Thank you.

Sincerely,

Steve Harris
President
H&S Environmental, LLC

Figure 2. Very Clear Effluent in Cell # 3

PERFORMANCE EVALUATION REPORT

Facility Name: The City of Hillsboro North Dakota Wastewater Lagoon System

Client: The City of Hillsboro, North Dakota, and The International Red River Board (IRRB)

Date of Field Sampling: September 22, 2021

Data Review:
Dissolved Oxygen, pH, Ammonia and Sludge Field Sampling Results
Intra-Pond BOD and Ammonia, RMB Labs, July 2021
Field Dissolved oxygen, pH, Temperature, Ammonia, Nitrate, Nitrite, and Alkalinity, and sludge blanket thickness by Hillsboro and H&S Environmental, LLC, September 22, 2021
US EPA ECHO DMR date from January 2016 to August 2021
Permit: NPDES Permit No. NDG 121903

Hillsboro, North Dakota:

Jim Anderson, Public Works Director
Mike Hovet, Operator

The International Red River Board:

Mr. Ted Priester, Executive Director

H&S Environmental, LLC: Steve Harris, President, Mesa, AZ

Report Prepared By:
Steve Harris,
President, H&S Environmental, LLC
October 27, 2021

Section 1
Introduction and Background

1.0 Scope and Purpose

In September 2021, H&S Environmental and Ted Priester met at the Hillsboro wastewater lagoon system to test the system's water quality and take samples for RMB Lab testing. After a thorough review of Hillsboro's field, lab, and DMR data, Steve Harris of H&S Environmental, LLC (H&S) prepared this performance evaluation.

The information used in this performance and optimization evaluation includes the following:

- Phone interviews, email contact, and in-person interviews with Jim Anderson, Public Works Director of Hillsboro, North Dakota, on the history and general condition of the lagoon system
- Analysis of 2016 through 2021 DMR data.
- The results of intra-pond nutrient sampling, dissolved oxygen sampling, sludge judging by H&S, Hillsboro, and Intra-pond BOD_5 testing by RMB Labs.

The purpose of this evaluation is to identify ways to improve the treatment process to meet permit limits in a long-term sustained manner.

This report will focus on methods to keep the Hillsboro system within permit limits. To determine if in-pond optimization is possible, H&S Environmental will analyze and evaluate lagoon system performance with respect to (i) historical data reviewed, (ii) additional data gathered from field testing and sampling, and (iii) a review of sampling and testing protocols practiced by Hillsboro North Dakota utility personnel.

This report covers the Hillsboro Lagoon System performance as it existed up to September 2021.

Findings

Section 2 – Findings

2.0 Findings

The results of intra-pond sampling performed by H&S and Hillsboro (September 22, 2021) are presented below.

Section 2 – Findings

1. Laboratory analysis by RMB Labs shows Effluent BOD_5 is within permit limits measuring 4 mg/l

2. Laboratory analysis by RMB Labs shows Effluent TSS is within permit limits at 2.5 mg/l

3. Effluent Ammonia tested 0.109 mg/l by H&S Environmental, LLC

4. Effluent Ortho-Phosphorous measured 2.94 mg/l by H&S Environmental, LLC

5. Three (3) mg/l of Effluent BOD_5 is caused by algae respiring in the BOD_5 test bottle. SBOD = 3

6. Dissolved Oxygen measured in the morning, before oxygen production through photosynthesis, measured between 10.02 and 12.58 mg/l in Cell # 1. In Cell # 2, dissolved oxygen measured between 6.18 and 7.94 mg/l. In Cell # 3, predawn DO measured 3.03 to 4.92 mg/l. At the time of field testing, Hillsboro could handle the daily waste load from the influent.

7. Long retentions times, algae assimilation, and high pH, along with nitrification, are the major ammonia removal pathways. Nitrification appears to play a role in ammonia removal in Cell # 1 at Hillsboro due to an $NBOD_5$ (BOD_5 – $CBOD_5$) of 8.7 mg/l. $NBOD_5$ is considered the relative number of nitrifying bacteria in a system.

8. pH as measured morning and afternoon was outside permit limits, and during the afternoon measured 9.15 at its highest point at the Cell # 3 discharge point.

9. Sludge averaged 0.75 feet in Cell # 1, 0.83 feet in Cell # 2, and Cell # 3 averaged 0.88 feet. Sludge volume in Cell # 1 is estimated to be 5,893,177 gallons. In Cell # 2, there are an estimated 6,592,287 gallons of sludge. Cell # 3, 2,646,955 gallons.

10. Retention time, assuming accumulated sludge and NO short-circuiting is two-hundred-fifty-nine (259) days. Calculated retention time is based on a flow of 0.150 MGD (from Jim Anderson, Public Works Director) and measured water depths.

11. Loading to the Hillsboro appears to be normal for a shallow facultative pond system in North Dakota: 12.2 lbs./acre/day based on 150,000 ADF and an average CBOD of 250 mg/l.

Section 3 – Recommendations - Continued

RECOMMENDATIONS

Based on the analysis of Intra-pond Field Sampling results and the analysis of DMR data, below are recommendations for improved stabilization pond performance for long-term sustained compliance using the existing wastewater stabilization pond system.

The object of the recommended changes to the Hillsboro wastewater lagoon system is intended to keep Hillsboro permit compliant in a long-term sustainable manner.

Five (5) recommendations for the Hillsboro North Dakota wastewater lagoon system are:

1) Sludge judge in five years
2) Prepare now for the inevitable expense of desludging the treatment cells. The size of the treatment cells will make desludging expensive, so begin to set aside money now for this costly operation.
3) Keep a close eye on the upward trends in BOD, TSS, and ammonia and desludge when these numbers approach permit limits
4) Quarterly perform intra-pond diagnostic BOD, TSS, Ammonia, and Nitrate to monitor the success of any changes. Remember, the lagoon system is subject to seasonal changes in the water temperature and length of the day. Therefore look to yearly changes in pond behavior for the success of any changes.

1) <u>Begin Now to Plan for Desludging the Treatment Cells</u>

Sludge has accumulated to 0.75 feet in Cell # 1. Typically sludge is removed when it reaches 1.5 feet to avoid benthal feedback…the feeding of algae cells with nutrients released from the sludge blanket.

Laboratory results show Cell # 1 BOD removal efficiency of seventy-four-point-four (74.5) % from the influent to the effluent of Cell # 1. Ideally, Cell # 1 should be removing eighty (80) % or more of the influent BOD. There was a 94.9% overall BOD_5 removal from the system. The Hillsboro lagoon system is BOD and TSS compliant, and ammonia leading to elevated effluent BOD_5 also shows good removal efficiency through the system. The influent BOD is dilute, seventy-eight-point-eight (78.8) mg/l. In the long run, it would pay Hillsboro to run a quarterly influent BOD to check the integrity of the collection system. If dilute influent BOD_5 persists, tighten up the collection system.

At current water levels, sludge in Cell # 1 occupies thirty-three-point-four (33.4) percent of the capacity. In Cell # 2, sludge occupies about twenty-eight-point-five (28.5) percent of the treatment cell's capacity; in Cell # 3, sludge occupies twenty-two-point-seven (22.7) percent. Sludge can cause elevated BOD if there is nutrient feedback from the sludge blanket.

Effluent TSS is compliant at 2.5 mg/l. The release of nutrients from a sludge blanket can feed algae growth causing high effluent TSS and CBOD. When there begins to be an upward trend in effluent ammonia, TSS, and CBOD, it means that sludge is feeding algae growth or the community is growing to place a greater load on the system. Loading comes from two sources; 1) the influent loading and 2) the sludge blanket. A sludge blanket is composed of dead algae, protozoa, and bacteria. As the sludge sits there and rots, it releases ammonia, phosphorous, nitrates, and carbon dioxide. These are fertilizers that feed algae. Because algae consume oxygen under dark conditions (the BOD_5 test and the pond at night), algae are the number one cause of BOD violations in the US.

Section 3 – Recommendations - Continued

2) Keep an Eye on Increasing Trends in Effluent TSS, BOD, and Ammonia

Increasing trends in effluent BOD, TSS, and ammonia are signs of benthal feedback; the release of nutrients causing algae growth leading to TSS, $CBOD_5$ violations, and problems with diminishing percent removal efficiency. Watch these numbers closely as a sign there is too much sludge.

3) Quarterly Perform Intra-pond Diagnostic BOD, TSS, Ammonia, and Nitrate to Monitor the Success of Any Changes.

Intra-pond testing is how to evaluate changes made to a lagoon system. Start by measuring effluent BOD, Ammonia, Nitrate, and DO at the effluent of all cells. When changes to the treatment system are made, judge performance based on improvements in intra-pond BOD_5, $CBOD_5$, Ammonia, Nitrate, and Dissolved Oxygen test results.

Operational Notes:

To evaluate and understand the effects of the changes that are made to the Hillsboro North Dakota wastewater lagoon system, BOD_5, $CBOD_5$, Temperature, Ammonia and Nitrate concentrations, DO, and pH must be routinely be made and recorded. These tests will enable the operators to make sound decisions when making changes to the system and monitor those changes for success.

Intra-pond testing will help operations staff focus on specific areas where problems (opportunities for optimization) occur. Pinpointing where, when, and why a problem occurs saves time and money and simplifies lagoon optimization for Ammonia and $CBOD_5$ removal.

More than any other process control test, Cell # 1 effluent BOD_5 removal efficiency and ammonia removal efficiency through each cell of the system will tell operations personnel when the influent loading is becoming a problem or if changes have taken effect. Determining removal efficiency requires pulling a BOD_5 sample from the Effluent of Cell # 1 while an influent BOD_5 sample is drawn and tested. Compare the two results. Cell # 1 removal efficiency should be at least eighty (80) percent. Operations staff should strive to keep Cell # 1 effluent BOD as low as possible to ensure good ammonia removal from the other treatment Cells in the system.

BOD_5 should also be measured from the effluents of Cells # 1, 2, and 3. $BOD_5 – CBOD_5 = NBOD_5$. $NBOD_5$ is the relative number of nitrifying bacteria in a system and denotes nitrification is or has the potential of occurring.

As much as possible, treatment should be “pushed back” to Cell # 1. Pushing BOD removal back to Cell # 1 is accomplished by adding sufficient DO to ensure DO is above two (2) mg/l at all times of the day and night, desludging, and stopping short-circuiting. Higher treatment levels in Cell # 1 will allow for better Ammonia and Nitrate removal in subsequent cells. Cell 2 should be for the conversion of Ammonia to Nitrate to Nitrogen gas and settling dead bacteria and algae cells clarifying the water. This objective is more easily accomplished by getting the most productivity out of Cell # 1 as possible.

An operator’s job is to discharge as few algae cells as possible and no ammonia. Currently, the Hillsboro lagoon system produces exceptional water quality during field testing and sampling and would be compliant with all permit limits except for pH.

Section 3 – Recommendations - Continued

Figure 3. Cell # 1 of the Hillsboro Wastewater Lagoon System.

Figure 4. Operator Mike Hovet Looking at Cell # 2 of the Hillsboro Wastewater System.

Figure 5. Cell # 3 of The Hillsboro Wastewater Lagoon System. Water in this cell is exceptionally clear.

Field Testing Data Analysis

Dissolved Oxygen Concentrations

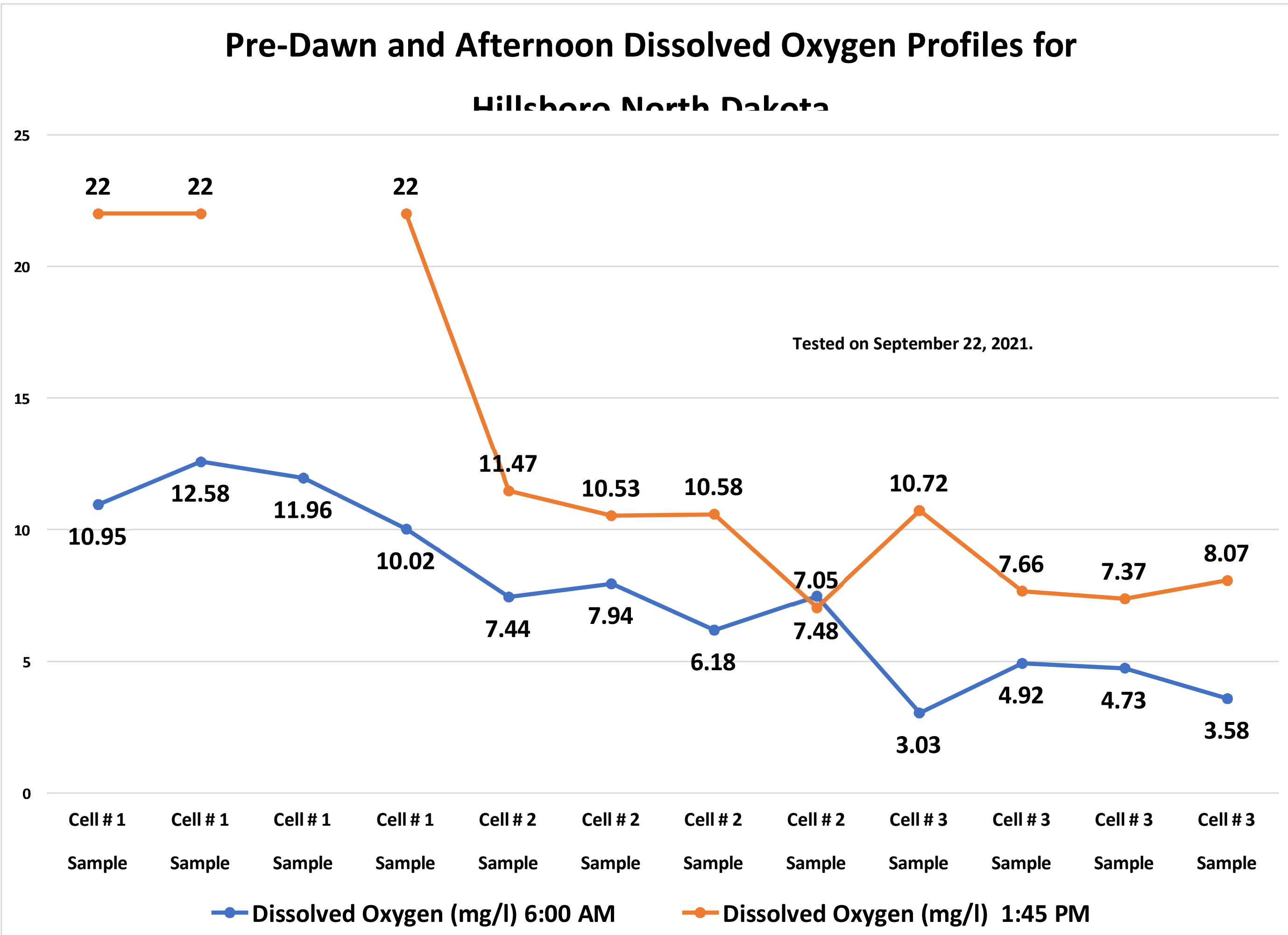


Figure 6. Predawn and Afternoon Dissolved Oxygen Concentrations.

Always keep dissolved oxygen concentrations above two (2) mg/l for greater $CBOD_5$, ammonia removal, odor control, and optimal performance.

There are two loading sources for the Hillsboro wastewater lagoon system, 1) the loading coming in daily, and 2) the sludge blanket. Nutrients are stored in the bodies of dead bacteria, algae, and protozoa that make up the sludge blanket. This sludge feeds nutrients and soluble BOD back into the water column, putting a strain on the system. This loading manifests itself in low dissolved oxygen concentrations and increasing effluent TSS, CBOD, and ammonia trends.

The chart above shows excellent oxygen production by the algae growing in the lagoons.,

Dissolved Oxygen Profile Taken by Boat from the Middle of Cell # 1

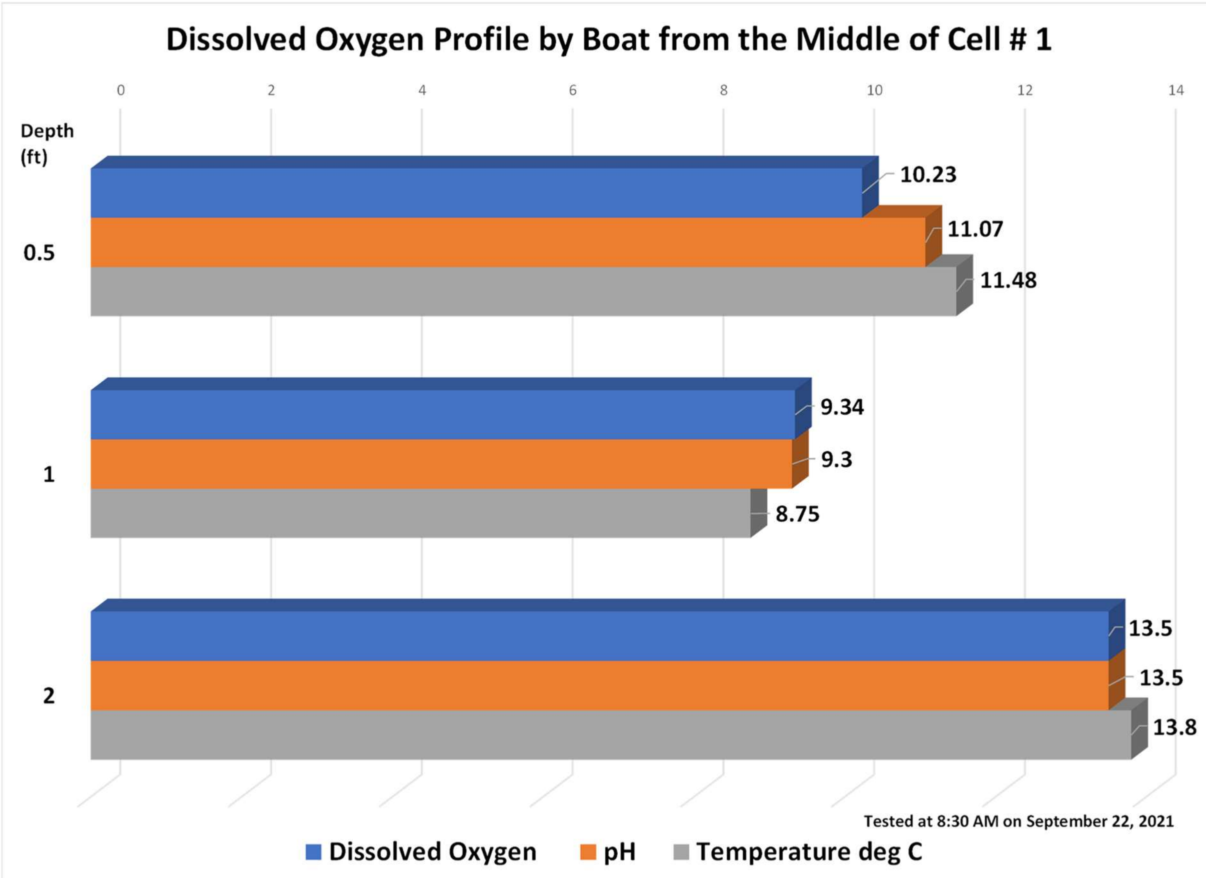
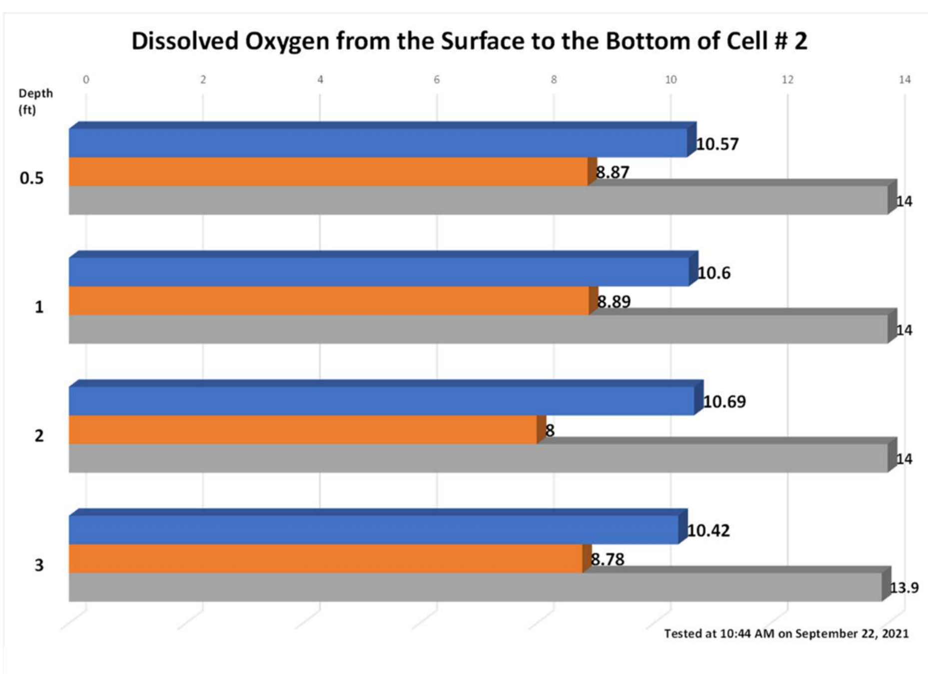


Figure 7. Cell # 1 Dissolved Oxygen Profile

This is the kind of dissolved oxygen concentrations operators want to see in their primary treatment cells before sunrise and oxygen production through photosynthesis. This level of oxygen is above saturation and is ideal.



RMB Laboratories Intra- Pond BOD_5 Test Results

On Wednesday, September 22, 2021, samples were delivered to RMB Labs for intra-pond BOD_5 analysis. Below are the results.

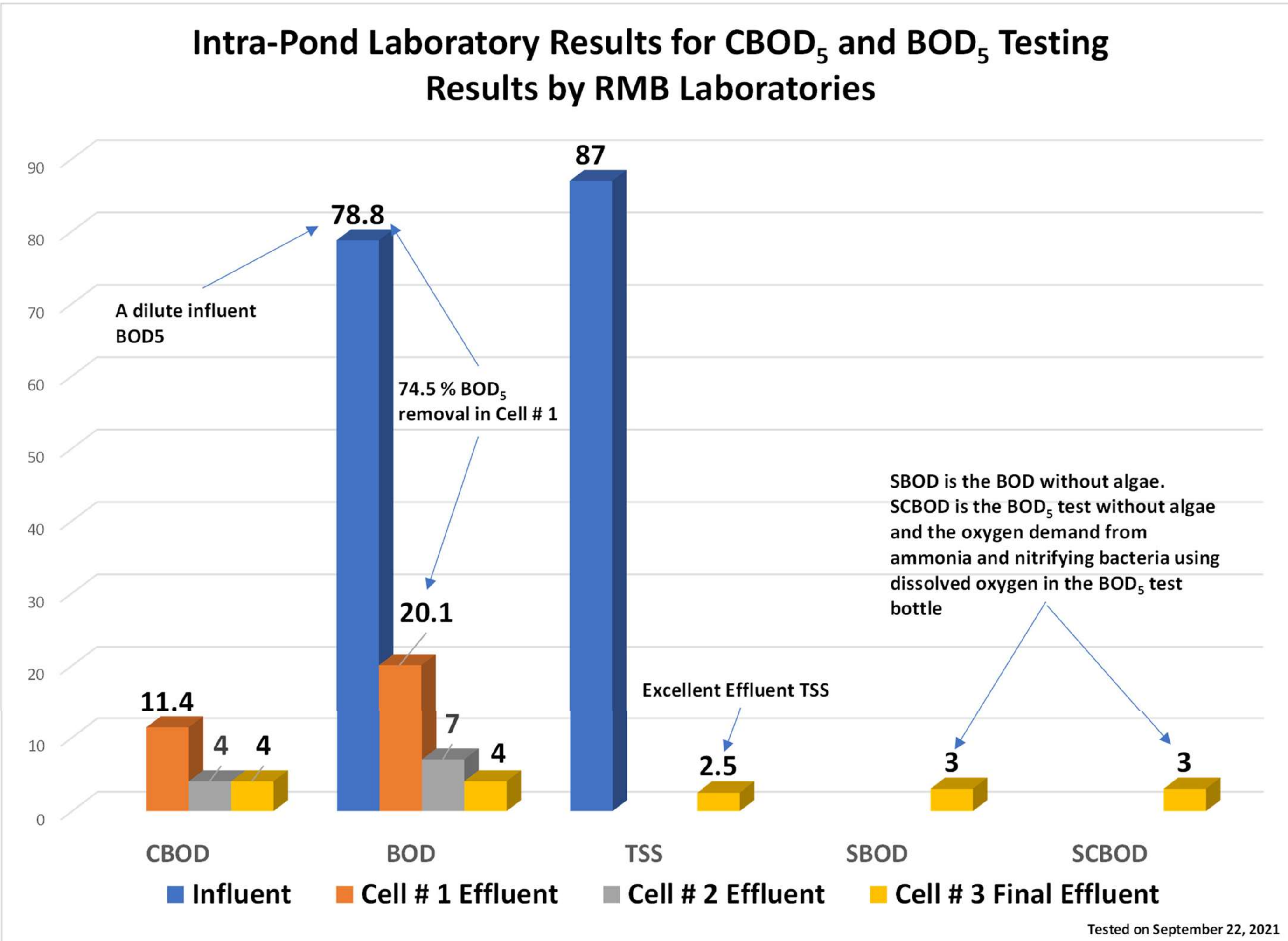


Figure 9. Intra-pond BOD_5 Results from RMB Labs

Benthal feedback is where the sludge feeds BOD_5, TSS, and algae growth by releasing nutrients once tied up in the cells of dead algae and bacteria that make up the sludge blanket.

Algae is the number one cause of BOD_5 violations in the US because algae consume oxygen for five (5) days under dark conditions in the BOD_5 test bottle and incubator. When the lights are off algae, switch to oxygen consumption. That is why the most meaningful Dissolved Oxygen test is performed during the morning before sunlight hits the pond system. The BOD without Algae (SBOD) is three (3) mg/l in Hillsboro, and the four (4) mg/l of TSS does not require much oxygen and does not significantly interfere with the effluent BOD numbers.

Field Nutrient Testing

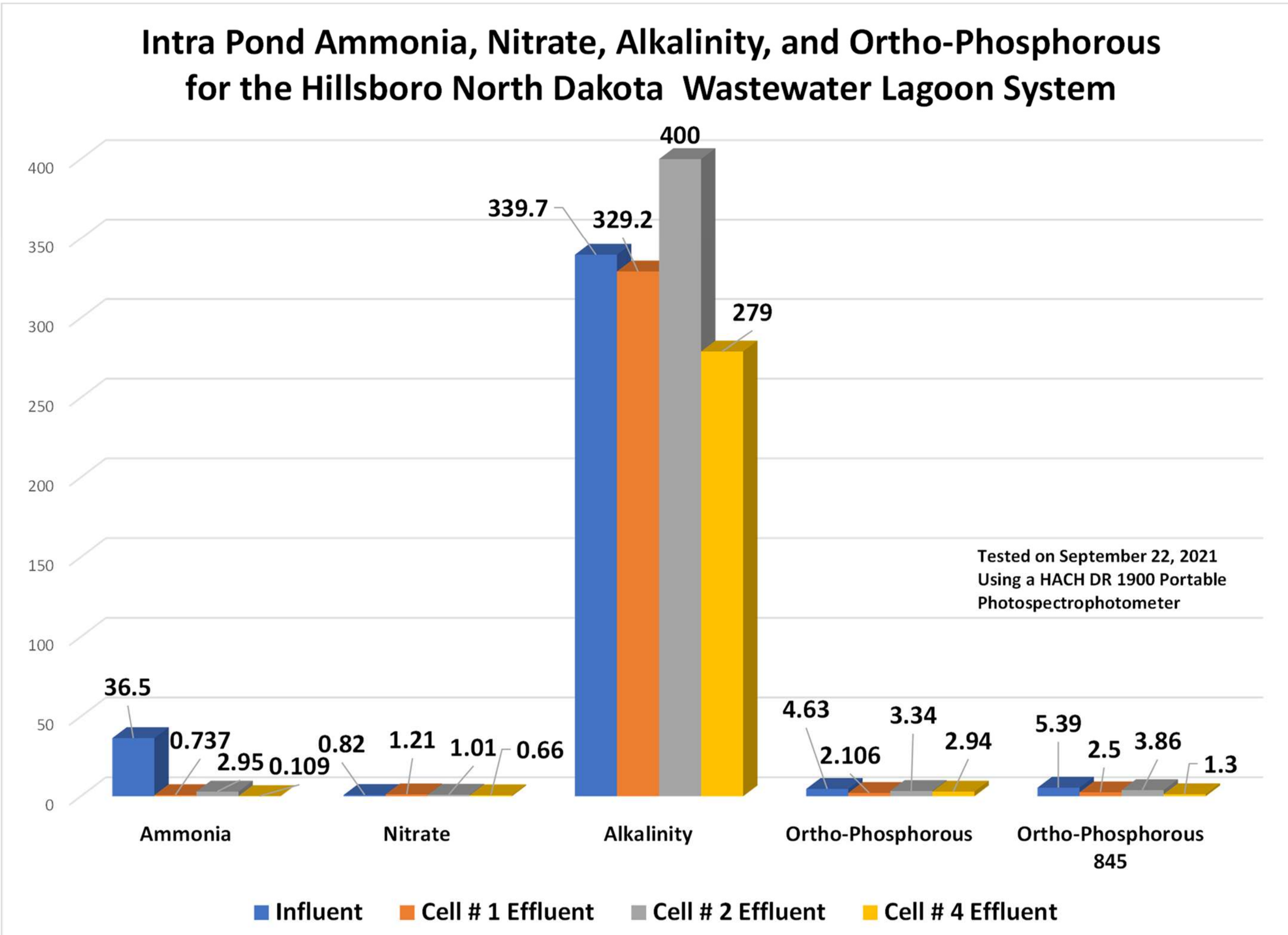


Figure 10. Intra-Pond Ammonia, Nitrate, Alkalinity, and Ortho-Phosphorous Results from Field Measurements

Ammonia removal is excellent. The primary ammonia removal pathway appears to be volatilization by high pH, algae assimilation, and then nitrification in Cells 1 & 2.

Sludge Accumulation

Hillsboro North Dakota								
Sludge Blanket Volume and Retention Time Summary								
Item	Units	**Cell # 1**	**Cell # 1A**	**Cell # 2**	**Cell # 2**	**Cell # 3**	**Cell # 3**	**Totals**
Bottom Length	feet	**1242**	**681**	**1234**	**1234**	**820**	**820**	
Bottom Width	feet	**925**	**300**	**979**	**243**	**590**	**205**	
Side Slopes	1 to	**3**	**3**	**3**	**3**	**3**	**3**	
Average Sludge Depth	feet	**0.75**	**0.75**	**0.83**	**0.83**	**0.88**	**0.88**	
As-Built Bottom Elevation	feet	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
As-Built Top-of-Bank Elevation	feet	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	
Bottom Area	sq ft	1,148,850	204,300	1,208,086	299,862	483,800	168,100	
Top of Sludge Length	feet	1246.5	685.5	1238.98	1238.98	825.28	825.28	
Top of Sludge Width	feet	929.5	304.5	983.98	247.98	595.28	210.28	
Top of Sludge Area	sq ft	1,158,622	208,735	1,219,132	307,242	491,273	173,540	
Sludge Volume	cu ft	865,302	154,888	1,007,295	251,948	429,032	150,322	2,708,465
Sludge Volume	**gallons**	**6,472,458**	**(579,281)**	**7,534,569**	**(942,282)**	**3,209,159**	**(562,204)**	**15,132,419**
Embankment Height	feet	7.00	7.00	7.00	7.00	7.00	7.00	
Freeboard Required	feet	**2**	**2**	**2**	**2**	**2**	**2**	
Useable Lagoon Depth / Volume of Remaining Water Cap after Sludge	**feet**	**1.50**	**1.50**	**2.07**	**2.07**	**2.99**	**2.99**	
Top of Water Max Length	feet	1272	711	1264	1274	850	235	
Top of Water Max Width	feet	955	330	1009	273	620	171	
Top of Water Max Area	sq ft	1,214,760	234,630	1,275,376	347,802	527,000	40,185	
Lagoon Volume	cu ft	1,772,708	329,198	2,570,383	670,332	1,511,146	311,386	6,853,766
Usable Remaining Lagoon Volume at Current Operating Depths with Sludge	**gallons**	**13,259,852**	**(1,231,200)**	**19,226,466**	**(2,507,042)**	**11,303,372**	**(1,164,584)**	**38,886,864**
AVE Daily Flow: 0.150 MGD (DMR)								
Actual Retention Time Based on Sludge Volume, Actual Operating Depths, and Remaining Water Cap Capacity	days	**88.40**	**-8.21**	**128.18**	**-16.71**	**75.36**	**-7.76**	**259.25**
Notes & Cautions:								
Treatment Cell bottoms were uneven.								
Rounded corners exist, square corners are used in the calculations above								
Averages of water depths and average sludge blanket thickness are used								
Slopes are assumed at 3:1								

Figure 11. Sludge Blanket Volume and Retention Time Calculations.

Section 4 – Field Data Analysis

The sludge survey procedure followed by H&S Environmental was performed using a survey level rod to measure the water depth at forty-five (45) sample points in the lagoon system. At the same time, an infrared sludge level detector set at medium was used to detect the top of the sludge blanket. Excel calculated the difference between the top of the water and the top of the sludge, effectively measuring sludge blanket thickness.

In Cell # 1, there has accumulated 5,893,177 gallons of sludge. In Cell # 2, 6,592,287 gallons of sludge and in Cell # 3, 2,646,955 gallons. This is a lot of sludge, and at an estimated 6.5% Total Solids concentration, that's 4,065 dry tons, and at $250/dry ton, that's $1,016,437 in sludge removal costs.

Aside from occupying valuable capacity and lowering a treatment cell's retention time, sludge releases nutrients and soluble BOD back into the water column. These nutrients feed TSS production through algae growth. Because they consume oxygen under the dark conditions of the BOD_5 test, algae can result in high BOD_5. The release of nutrients from sludge feeds algae growth resulting in TSS permit violations.

Once sludge reaches about eighteen (18) inches in thickness, it is time to consider removal to prevent nutrient feedback causing problems with increases in algae growth leading to TSS problems.

Sludge removal options include dredging, pressing or centrifuging, and hauling off-site, as well as removing in situ with chemical oxidizing agents. Each method has its place. Sludge can also be pumped out and applied to a Geo-Tube or drying bed to dry on-site for two (2) years. Drying on-site allows for the removal of the water, reducing tipping fees and hauling costs. When dredging or drying, and scraping, the treatment cell must typically be taken offline.

Dredging mixes a treatment cell releasing Ammonia, Nitrates, phosphate, and CO2 to stimulate algae and bacteria growth. The filtrate from a belt press will concentrate nutrients as it squeezes sludge, creating a stream of nutrient-rich water that will load the plant. This nutrient-rich filtrate stream will, in most cases, cause a crash in DO and create odors. Be aware of the centrate or filtrate coming off the centrifuge, press, or weepage from a Geo-tube or runoff from a drying bed. Add air to the remaining working treatment cells when desludging. Keeping air above two (2) mg/l will keep odors and nutrient loading to a minimum.

If time permitted, mixing the sludge blanket and adding agricultural stubble breakdown chemistries can remove several feet of sludge over time. Mixing and chemical agents will not remove sand grit or gravel and leave dead bacteria bodies (Humus). The disadvantage of treating in place by mixing and adding is that you run the risk of freeing Ammonia, Nitrate, phosphate, CO_2, and organic acids to feed an algae bloom. Consult an expert before mixing a treatment cell. There are proven chemical additives from the agricultural industry that can accelerate sludge removal on-site associated with mixing.

Aeration and Dissolved Oxygen

There are seven (7) indicators that follow low dissolved oxygen levels in pond systems generally:

1) Poor BOD_5 removal efficiency
2) Low ammonia removal efficiency
3) Odors
4) Popping sludge in the treatment Cells
5) *Daphnia* turned red in the treatment Cells
6) Low DO measurements both day **and** night. The best, most meaningful time to measure DO is before sunrise, before algae have had the chance to produce dissolved oxygen
7) Increasing trends in effluent BOD_5 after all the Cells have been desludged

Dissolved oxygen measurements taken at the surface may not tell the whole story. While the surface water may appear to have sufficient DO, it may be anoxic just below the surface, beginning two to three feet below the surface. Measuring Dissolved Oxygen by boat in the middle of a treatment cell from the surface to the bottom at the sludge water interface is the best way to perform a DO profile. This type of DO profile is also best performed at or before sunrise.

Figure 12. Drought Conditions Have Lowered the Water Levels at Hillsboro

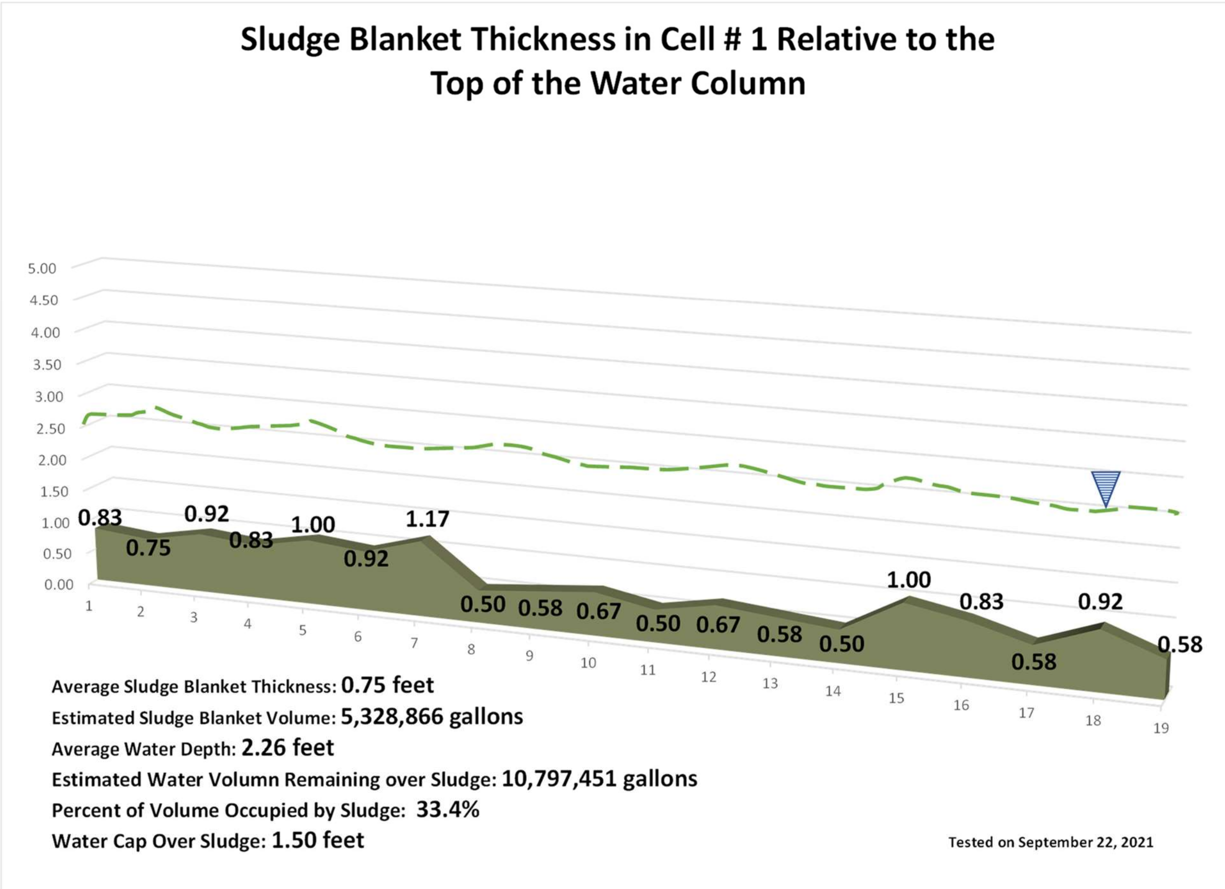


Figure 13. Cell # 1 Sludge Blanket Relative to the Top of the Water Column as Measured on September 22, 2021

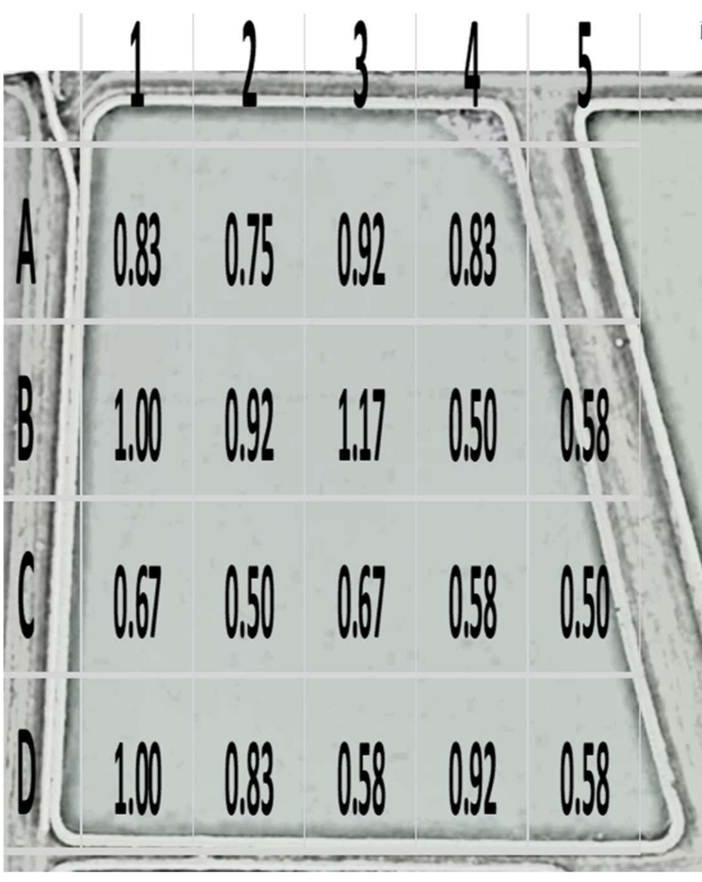


Figure 14. Sludge Blanket Thickness Locations for Cell # 1 of the Hillsboro Wastewater Lagoon System

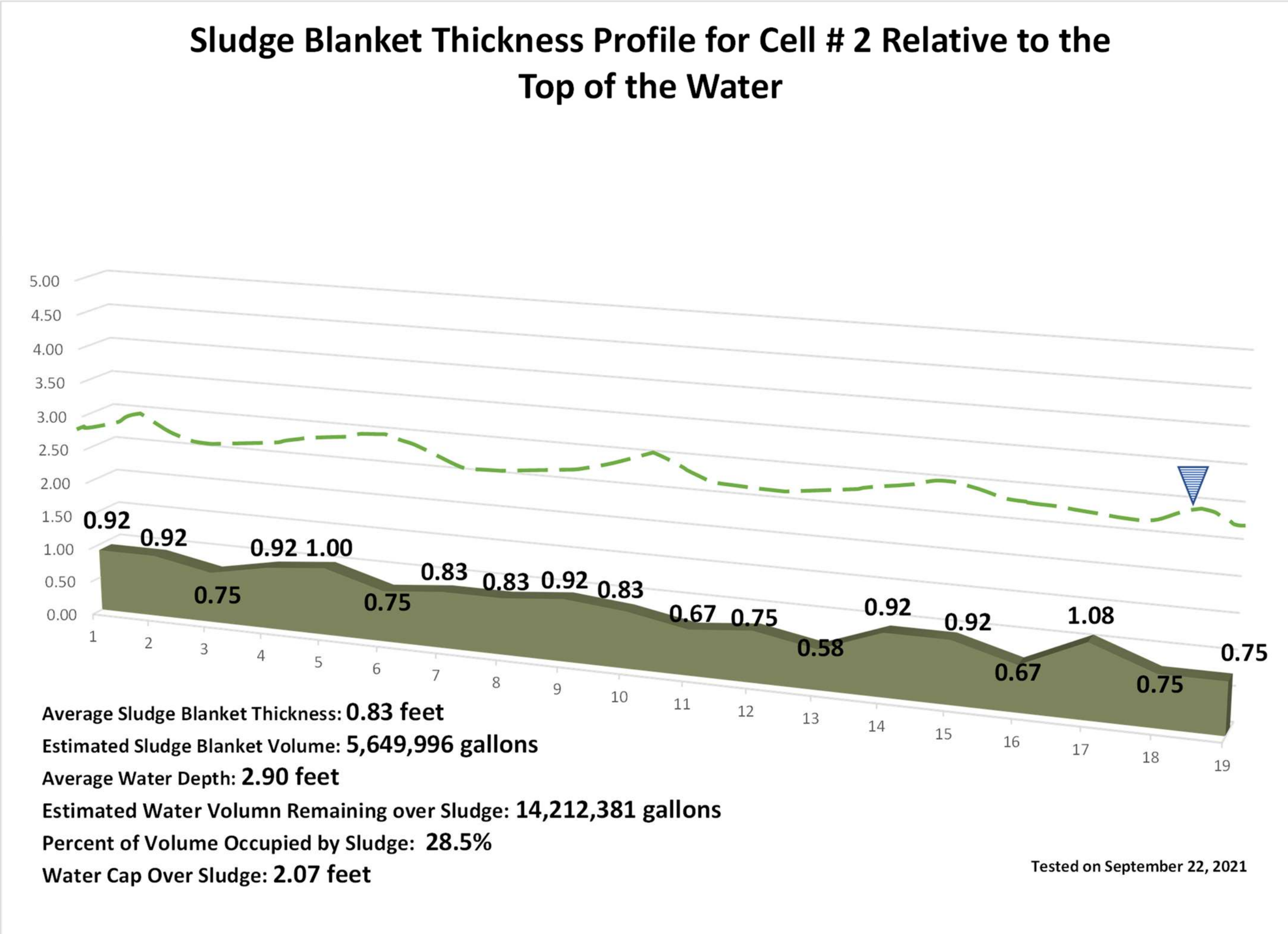


Figure 15. Cell # 2 Sludge Blanket Thickness Profile Relative to the Top of the Water

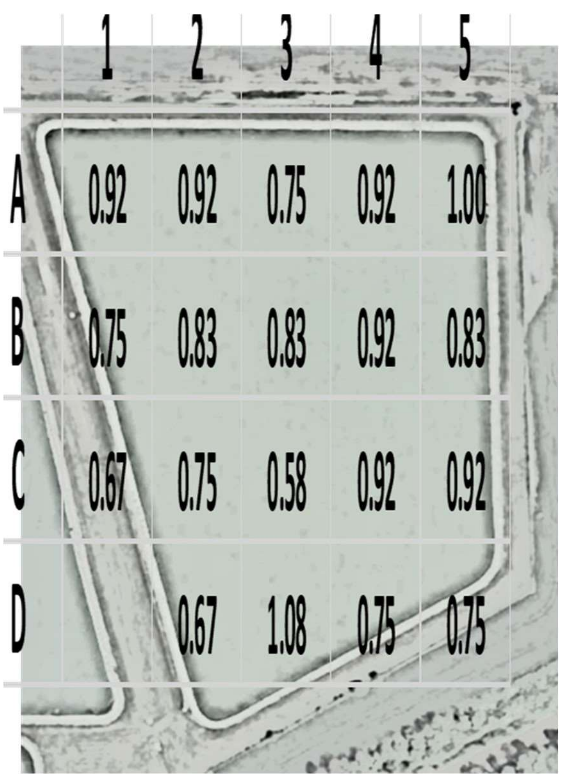


Figure 13. Sludge Blanket Thickness Locations for Cell # 2

Cell # 3 has accumulated 0.88 feet of sludge.

Sludge has a powerful impact on the effluent water quality of lagoon systems and should not be allowed to accumulate past eighteen (18) inches. Because it is so expensive to remove, the City of Hillsboro should begin to save for the inevitability of sludge removal.

Lagoons fail for two (2) main reasons; 1) Poor hydraulic design (short-circuiting) and 2) Sludge accumulation.

Short-circuiting is the worst thing that can happen to a lagoon system short of someone dumping toxic waste in the system. Sludge is the second worst thing that can affect effluent quality. Sludge stores the nutrients once assimilated and then releases them back to the water column as the dead algae and bacteria cells lyse.

Algae growth cause CBOD problems by consuming oxygen, not making it, when the lights are off. For five (5) days, a sample sits in a BOD_5 test bottle under dark conditions, and algae consume oxygen over those five (5) days inflating the BOD_5 test result. Sludge feeds algae growth, and algae growth leads to TSS violations and BOD problems because of this.

In the New England States, there is a mandate to remove sludge after it reaches eighteen (18) inches in thickness because of the problems it creates.

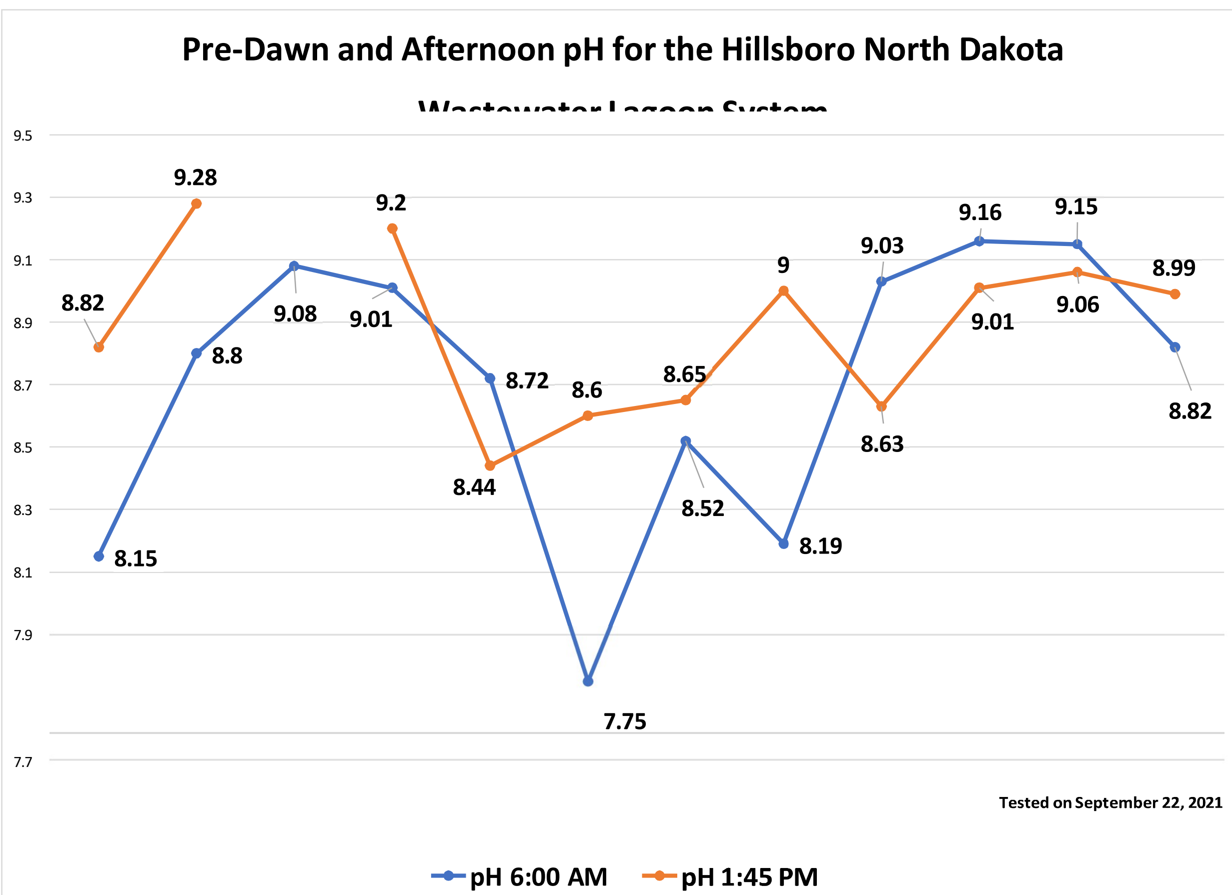


Figure 17. Morning and Afternoon pH

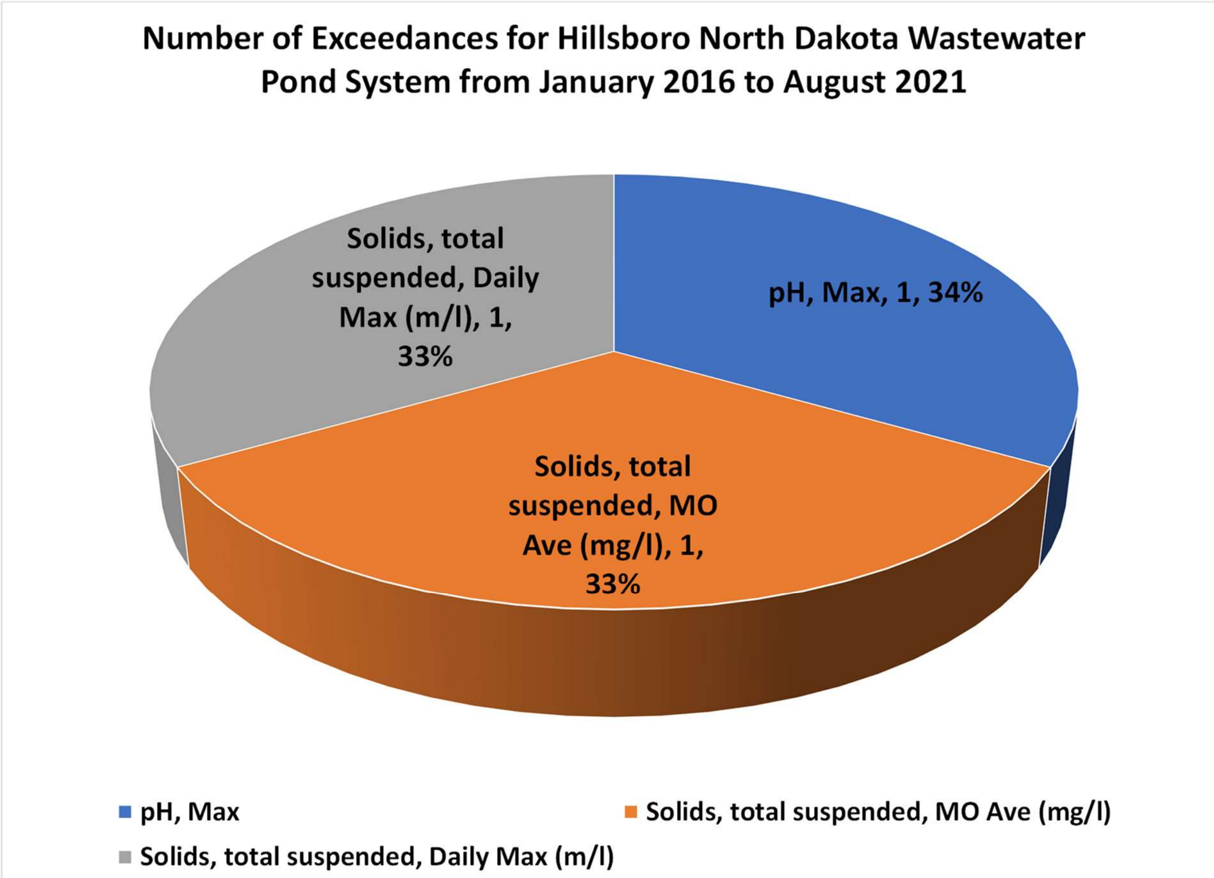


Figure 18. Exceedances by Type, Number of Violations, and Percent Occurance

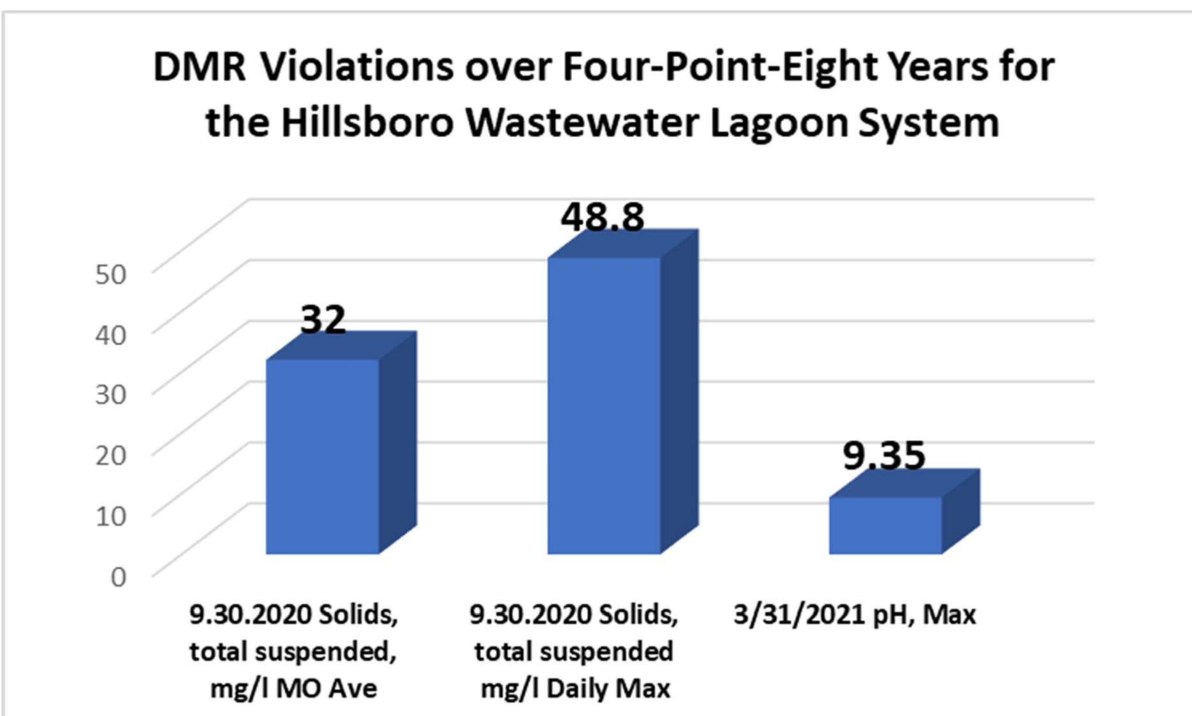


Figure 19. Exceedances by Type and Date

Section 5 – Summary

The Hillsboro North Dakota wastewater pond system produces exceptional effluent, and the plant is run by competent operators doing an excellent job. There is not much critical to say about this lagoon system as everything is in good working order. The pond system is healthy and functioning well.

Typically Hillsboro meets permit limits because it holds water long enough to exhaust the nutrients causing permit limit violations. Sixty-seven (67) percent of Hillsboro permit violations are for TSS violations occurring on one (1) day. If TSS problems persist, make sure effluent discharge is pulled from as low in the water profile without picking up sludge. Make sure the discharge is made from a pipe one (1) foot past the toe of the dike and up off the bottom of the discharge cell one (1) foot.

One (1) day of field testing shows a dilute influent resulting from an old leaky collection system. Many of the best upgrades for a lagoon system are made in the collection system. Begin to take quarterly influent BODs samples observing the concentrations. If BOD_5 and TSS concentrations are below 100, begin to tighten the collection system.

At the time of field testing, all limits were within permitted limits except for pH. Hillsboro can neutralize the effluent with muriatic acid to get the pH within permit limits if a discharge is needed.

To keep within permit limits, discharge as few algae cells as possible and no ammonia.

Remove sludge from the Cells when TSS and $CBOD_5$ removal efficiency consistently begins to drop below 85%.

Section 6 – Action Items

The recommendations outlined in this report offer solutions for meeting permit limits in a long-term sustainable fashion.

Four (4) Action Items are recommended for the Hillsboro North Dakota wastewater lagoon system, and they are:

1) Tighten the collection system to reduce dilute influent TSS and $CBOD_5$. Quarterly test for influent BOD_5 to monitor the condition of the collection system
2) Plan to desludge the treatment cells in the next ten (10) years
3) Closely monitor the trends in water quality permit parameters. When they get close to permit limits, it is time to desludge
4) Quarterly perform intra-pond diagnostic BOD, Ammonia, and Nitrate sampling between each treatment cell to understand the nature of the system.

Section 7 – Conclusions

CONCLUSIONS

The Hillsboro wastewater lagoon system is run by a competent crew doing a fine job in keeping the system within permit limitations. The pond system is healthy and is generally working well.

There is a where, a when, and a why to lagoon problem solving and optimization. Determining where treatment is not occurring is essential to optimizing Hillsboro, North Dakota's wastewater lagoon system for continued sustainable permit compliance.
Please see Diagnostic BODs in the attachments and commit to routinely performing these kinds of tests.

Thank you for the opportunity to serve the good people of Hillsboro, North Dakota.

Steve Harris President
H&S Environmental, LLC

Attachments

1) Diagnostic BODs
2) Algae's Contribution to the BOD_5 Test Result
3) The Importance of Mixing Lagoon Sludge Blankets

References

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US EPA Contract No. EP-C-08015 Work Assignment 2-54, Water and energy Audit Report for Hillsboro North Dakota Nation water and wastewater facilities, final report December 1 20, 2010, Prepared by the Cadmus Group, Inc., Watertown, MA.

- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization
- Training

2122 East Leland Circle Mesa, AZ 85213 1 (480) 314-8410

H&S Environmental, LLC.

Date: November 4, 2021

Ted Priester
Executive Director
Red River Basin Commission
1120 28th Avenue N, Suite B
Fargo, North Dakota 58201

Re: Performance Evaluation of the Mahnomen Minnesota Wastewater Lagoon System

Ted,

Enclosed is the November 4, 2021 report for H&S Environmental's (H&S) performance evaluation of the Mahnomen Minnesota Wastewater Lagoon System

The purpose of this report is to identify operational conditions and practices that should prevail to keep the effluent of the Mahnomen Wastewater Lagoon System within permit limits.

All facility data, sludge depth data, and other field data used in this report were compiled by Mahnomen and H&S Environmental, LLC (H&S) with the help of the Minnesota Rural Water Association.

The conclusions reached in this performance evaluation are based on five (5) primary data sources:

1) The results of intra-pond biological oxygen demand (BOD_5) testing by RMB Environmental Laboratories, Inc.
2) The analysis of six-point-one-seven (6.17) years of DMR data from the Minnesota Pollution Control Agencies' Wastewater Data Browser database
3) Field-testing of Ammonia, Nitrate, Alkalinity, Dissolved Oxygen, and pH results by Mahnomen and H&S Environmental, LLC
4) Sludge judging results by Frank Stuemke of the Minnesota Rural Water Association and H&S Environmental, LLC
5) DEQ Permit # MNT 024066, November 1, 2021, to October 31, 2021

Performance Evaluation of the Mahnomen Minnesota Wastewater Lagoon System

The City of Mahnomen, Minnesota wastewater facility is located at
47 17 47.86N, 95 57 51,89W

Permit Number MNT 024066

November 4, 2021

Prepared for

The International Red River Board

Project Title:
Supporting the IRRB's Nutrient Management Strategy Through Workshops and Technical Assistance in the Red River Basin

Prepared by
H&S Environmental, LLC
Steve Harris, President

This document was prepared under contract with the IRRB

Disclaimer

This document assumes basic wastewater operations knowledge, skills, understanding, and compliance with applicable federal and state permit limits.

Acknowledgments

This performance evaluation was prepared with assistance from Ted Priester, Executive Director, Red River Basin Commission

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Figure 1. The Mahnomen Minnesota, 4-Cell Facultative Wastewater Lagoon System

Executive Summary:

This report will focus on the results of field nutrient testing by Scott Zortman (Mahnomen), H&S Environmental, LLC (H&S), sludge judging by H&S and Frank Stuemke of the Minnesota Rural Water Association, laboratory BOD_5 analysis by RMB Laboratories, Inc, as well as six (6) years of DMR data from Minnesota Pollution Control Agencies' Wastewater Data Browser for recommendations on optimizing the Mahnomen wastewater lagoon system.

Field and laboratory samples were taken directly from the transfer structures of each treatment cell. The data from these samples show that the final effluent $CBOD_5$ and TSS are compliant and within permit limits. Effluent Ammonia was 3.20 mg/l, Soluble BOD was three (3) mg/l, and Ortho Phosphorous was between 3.5 and 4.0 mg/l. Dissolved oxygen before sunrise in Cell # 1 was less than 0.75 to 1.0 mg/l on the day of field testing. In Cell # 1, dissolved oxygen levels recovered to over three-and-a-half (3.5) mg/l during the afternoon. Effluent pH was compliant on the day of field testing.

The primary ammonia removal pathway appears to result from nitrification, but volatilization through high pH and assimilation by algae also remove ammonia. There is a one-hundred and seventy-three (173) day retention time at current water depths in the Mahnomen lagoon system, giving the water time to exhaust nutrients producing clean water.

If Mahnomen were required to discharge on the day of field testing and sampling, it would meet permit limits for BOD_5, TSS, and pH. Mahnomen typically produces an excellent effluent water quality.

Field testing of Dissolved Oxygen (DO) showed sufficient concentrations for half of the day to stabilize influent $CBOD_5$, TSS, and ammonia. The Primary Treatment Cell was anoxic during the morning. If problems with odors occur in Cell # 1, water high in DO can be recirculated back to Cell # 1 from Cell # 3. Cell # 3 DO at 2:30 PM was 13.5 mg/l.

Ammonia and Ortho-Phosphorous showed progressive reduction through all four (4) cells of the treatment system with feedback beginning at the effluent of Cell # 2 and running through Cells 3 & 4.

No treatment cells require sludge removal at this time. There is ammonia and ortho-phosphorous feedback (increase) from the effluent of Cell # 2 to Cell # 4. It could be a sign of accumulated sludge releasing nutrients from the sludge blanket.

Cells 1-4 should be re-sludge judged in three (3) to five (5) years to estimate sludge accumulation rates and to determine when sludge will reach eighteen (18) inches in thickness. Because of the volume and considerable expense, it is best to set aside money now for this expensive operation. Sludge should be removed when effluent water quality approaches permit limits. Sludge has accumulated in Cell # 1 to an average of 0.57 feet, Cell # 2 to 0.84 feet, and Cell # 3 to 0.80. Cell # 4 was not sludge profiled because of the shallow water cap.

Analysis of six (6) years of DMR data shows an increasing influent TSS and a decreasing trend in influent $CBOD_5$. Influent Monthly Flow is also decreasing over time. The trend in effluent $CBOD_5$ and TSS in mass and concentration (lbs. and mg/l) in the 6.4-Acre pond is increasing. Dissolved oxygen, pH, and Total Phosphorous are also increasing yearly in measures of concentration and mass. Watch these numbers closely.

In the 19-Acre pond, mass and concentration measures of influent TSS and $CBOD_5$ are decreasing. Influent Total Phosphorous decreases over the same period, and dissolved oxygen and flow decrease over the same period. Effluent Total Phosphorous and Monthly Average TSS and $CBOD_5$ in kg/day and mg/l also decrease over time.

Statistical analysis shows no correlation between any of the measured DMR data

Thank you.

Sincerely,

Steve Harris
President
H&S Environmental, LLC

PERFORMANCE EVALUATION REPORT

Facility Name: The City of Mahnomen Minnesota Wastewater Lagoon System

Client: The City of Mahnomen, Minnesota, and The International Red River Board (IRRB)

Date of Field Testing: September 24, 2021

Data Review:
Intra-Pond BOD and Ammonia, RMB Labs, September 2021
Field Dissolved oxygen, pH, Temperature, Ammonia, Nitrate, Nitrite, and alkalinity, and sludge blanket thickness by Mahnomen and H&S Environmental, LLC, September 23, 2021
MNWPCA Wastewater Data Browser from April 2015 to June 2021
Permit: NPDES Permit No. MNT024066

Mahnomen, Minnesota:

Scott Zortman, Wastewater Operations

The International Red River Board:

Mr. Ted Priester, Executive Director

H&S Environmental, LLC: Steve Harris, President, Mesa, AZ

Report Prepared By:
Steve Harris,
President, H&S Environmental, LLC
November 4, 2021

Section 1

Introduction and Background

1.0 Scope and Purpose

In September 2021, H&S Environmental visited the Mahnomen wastewater lagoon system to test the system's water quality and take samples for RMB Lab testing. After thoroughly reviewing Mahnomen's field, lab, and DMR data, Steve Harris of H&S Environmental, LLC (H&S) prepared this performance evaluation.

The information used in this performance and optimization evaluation includes the following:

- Phone interviews, email contact, and in-person interviews with Scott Zortman of Mahnomen, Minnesota, on the history and general condition of the lagoon system
- Analysis of 2015 through 2021 DMR data.
- The results of intra-pond nutrient sampling, dissolved oxygen sampling, sludge judging by H&S, Mahnomen, MN Rural Water, and Intra-pond BOD_5 testing by RMB Labs.

The purpose of this evaluation is to identify ways to improve the treatment process to meet permit limits in a long-term sustained manner.

This report will focus on methods of keeping the Mahnomen lagoon system within permit limits. To determine if in-pond optimization is possible, H&S Environmental will analyze and evaluate lagoon system performance with respect to (i) historical data reviewed, (ii) additional data gathered from field testing and sampling, and (iii) a review of sampling and testing protocols practiced by Mahnomen Minnesota utility personnel.

This report covers the Mahnomen Lagoon System performance as it existed up to September 2021.

Findings

Section 2 – Findings

2.0 Findings

The results of intra-pond sampling performed by H&S and Mahnomen (September 24, 2021) are presented below.

Section 2 – Findings

1. Laboratory analysis by RMB Labs shows Effluent BOD_5 is within permit limits at 15.3 mg/l

2. Laboratory analysis by RMB Labs shows Effluent TSS is within permit limits at 5.2 mg/l

3. Effluent Ammonia 3.2 mg/l and tested by H&S & Scott Zortman with the City of Mahnomen

4. Effluent Ortho-Phosphorous measured between 3.5 and 4.0 mg/l

5. Three (3) mg/l of Effluent BOD_5 is caused by algae respiring in the BOD_5 test bottle. SBOD = 3

6. Dissolved Oxygen measured in the morning, before oxygen production through photosynthesis, measured between 0.75 and 1.0 mg/l in Cell # 1. In Cell # 2, Dissolved Oxygen measured between 0.74 and 1.19 mg/l. In Cell # 3, predawn DO measured .8 to 8.92 mg/l, and in Cell # 4 before sunrise dissolved oxygen measured between .39 and 4.54 mg/l.

7. Long retentions times, algae assimilation, and high pH, along with nitrification, are the major ammonia removal pathways. Nitrification does not appear to play a significant role in ammonia removal at Mahnomen due to the lack of nitrate production and low $NBOD_5$ (BOD_5 – $CBOD_5$). $NBOD_5$ is considered the relative number of nitrifying bacteria in a system.

8. pH as measured morning and afternoon was within permit limits in Cell # 4

9. Sludge averaged 0.57 feet in Cell # 1 and 0.84 feet in Cell # 2, and 0.80 in Cell # 3. Cell # 4 was not sludge profile because of the lack of a water cap sufficient to float a boat. Sludge volume in Cell # 1 is estimated to be 2,709,622 gallons. In Cell # 2, there are an estimated 2,313,073 gallons of sludge. In Cell # 3 there is estimated to be 3,285,073 gallons. Cell # 4 was not profiled.

10. Retention time, assuming accumulated sludge and NO short-circuiting is one-hundred-seventy-three (173) days. Calculated retention time is based on a flow of 0.237 MGD (from DMR Data submitted by Mahnomen) and measured water depths.

11. The Trends in Influent Monthly Average Flow, $CBOD_5$, TSS, and Total Phosphorous are decreasing

12. The Trends in Effluent pH, TSS, $CBOD_5$, and Total Phosphorous are increasing in both the 6.4 and 19-Acre Ponds

13. Loading to the Mahnomen appears to be a bit high for a shallow facultative pond system in Minnesota: 32.3 lbs./acre based on .237 ADF and an average $CBOD_5$ of 250 mg/l using a 15.3- acre primary treatment cell. In Minnesota, loading is typically about 22 lbs/acre/day; using an average 188.3 mg/l influent $CBOD_5$ (five (5) years of influent DMR data) loading is: 24.3 lbs/acre/day

14. There are no statistically significant relationships between any of the DMR variables found in the data set from in the MN Pollution Control Wastewater Data Browser

Section 3 – Recommendations - Continued

RECOMMENDATIONS

Based on the analysis of Intra-pond Field Sampling results and the analysis of DMR data, below are recommendations for improved stabilization pond performance for long-term sustained compliance using the existing wastewater stabilization pond system.

The object of the recommended changes to the Mahnomen wastewater lagoon system is intended to keep Mahnomen permit compliant in a long-term sustainable manner.

Three (3) recommendations for the Mahnomen Minnesota wastewater lagoon system are:

1) Keep a close eye on the upward trends in BOD, TSS, and pH and desludge when these numbers approach permit limits
2) If odors occur or more $CBOD_5$ removal from Cell # 1 is desired, water high in DO can be recirculated back to Cell # 1 from Cell # 3, which has a DO of over thirteen (13) mg/l during the afternoon.
3) Quarterly perform intra-pond diagnostic BOD, TSS, Ammonia, and Nitrate to monitor the success of any changes. Remember, the lagoon system is subject to seasonal changes in the water temperature and length of the day. Therefore look to yearly changes in pond behavior for the success of any changes.

1) **Keep an Eye on Increasing Trends in Effluent TSS, BOD, and Ammonia. Begin Now to Plan for Desludging the Treatment Cells**

Lab results show increasing $CBOD_5$ and ammonia concentrations from the effluent of Cell # 2 through Cell # 4. Sludge has accumulated to 0.57 feet in Cell # 1. 0.84 feet in Cell # 2, and 0.80 feet in Cell # 3. Typically sludge is removed when it reaches 1.5 feet to avoid benthal feedback…the feeding of algae cells with nutrients released from the sludge blanket.

Laboratory results show excellent Cell # 1 CBOD removal (97.5%) from the influent to the effluent of Cell # 1.

Removal efficiency drops to 90.6% overall $CBOD_5$ removal at the final Cell # 4 effluent. The Mahnomen lagoon system is currently $CBOD_5$ and TSS compliant but continue to watch for decreasing effluent water quality as a sign it's time to remove sludge.

At current water levels, sludge in Cell # 1 occupies seventeen (17) percent of the Cell's capacity. In Cell # 2, sludge occupies about twenty-seven-point-five (27.5) percent of the treatment Cell's capacity and twenty-seven (27) % of Cell # 3's capacity. Sludge can cause elevated $CBOD_5$ if there is nutrient feedback from the sludge blanket.

Effluent TSS from field testing results is compliant at 5.2 mg/l but is increasing yearly. Effluent $CBOD_5$ from field testing results was 15.3 mg/l.

Section 3 – Recommendations - Continued

Increasing trends in effluent BOD, TSS, pH, and Ammonia are signs of benthal feedback; the release of nutrients causing algae growth leading to TSS, $CBOD_5$, and pH violations, and problems with diminishing percent removal efficiency. Watch these numbers closely.

2) <u>Recirculate Water High in Dissolved Oxygen from Cell 2 or 3 Back to Cell # 1</u>

If odors result from the low early morning dissolved oxygen concentrations, water high in dissolved oxygen can be recirculated from Cell # 3 to Cell # 1 during the afternoon when Cell # 3 DO is the highest. Loading comes from two (2) sources, 1) the sludge and 2) the daily influent BOD_5 loading.

In Cell # 1, at 4:56 AM in the morning, dissolved oxygen concentrations were between 0.75 and 1.00 mg/l. In Cell # 3, DO levels were higher, measuring between .80 and 8.92 mg/l at the same time. DO in Cell # 3 is a resource and can be recirculated back to Cell # 1 to control odors and improve ammonia removal. A simple two (2) inch trash pump is all that is needed. In the afternoon, after 2:30 PM PM, water high in DO can be recirculated back to Cell # 1 using a trash pump to stop odors and provide the oxygen necessary for improvement in water quality. Dissolved oxygen in the afternoon measured 13.5 mg/l.

Figure 2. Cell # 4 of the Mahnomen Wastewater Lagoon System.

4. <u>Quarterly Perform Intra-pond Diagnostic BOD, TSS, Ammonia, and Nitrate to Monitor the Success of Any Changes.</u>

Intra-pond testing is how to evaluate changes made to a lagoon system. Start by measuring effluent BOD, Ammonia, Nitrate, and DO at the effluent of all cells. When changes to the treatment system are made, judge performance based on improvements in intra-pond BOD_5, $CBOD_5$, Ammonia, Nitrate, and Dissolved Oxygen test results.

<u>Operational Notes:</u>

To evaluate and understand the effects of the changes that are made to the Mahnomen Minnesota wastewater lagoon system, BOD_5, $CBOD_5$, Temperature, Ammonia and Nitrate concentrations, DO, and pH must be routinely be made and recorded. These tests will enable the operators to make sound decisions when making changes to the system and monitor those changes for success.

Section 3 – Recommendations - Continued

Intra-pond testing will help operations staff focus on specific areas where problems (opportunities for optimization) occur. Pinpointing where, when, and why a problem occurs saves time and money and simplifies lagoon optimization for Ammonia and $CBOD_5$ removal.

More than any other process control test, Cell # 1 effluent BOD_5 removal efficiency, and ammonia removal efficiency through each Cell of the system will tell operations personnel when the influent loading is becoming a problem or if changes have taken effect. Determining removal efficiency requires pulling a BOD_5 sample from the Effluent of Cell # 1 while an influent BOD_5 sample is drawn and tested. Compare the two results. Cell # 1 removal efficiency should be at least eighty (80) percent. Operations staff should strive to keep Cell # 1 effluent BOD to less than 30 mg/l to ensure good ammonia removal from the other treatment Cells in the system.

BOD_5 and $CBOD_5$ should also be measured from the effluents of Cells # 1, 2, 3, and 4. $BOD_5 - CBOD_5 = NBOD_5$. $NBOD_5$ is the relative number of nitrifying bacteria in a system and denotes nitrification is or has the potential of occurring.

As much as possible, treatment should be "pushed back" to Cell # 1. Pushing BOD removal back to Cell # 1 is accomplished by adding sufficient DO to ensure it is above two (2) mg/l at all times of the day and night, desludging and stopping short-circuiting. Higher treatment levels in Cell # 1 will allow for better ammonia and nitrate removal in subsequent cells. Cell 3 should be for the conversion of ammonia to nitrate to nitrogen gas, and Cell # 4 is for killing pathogens through UVB, high pH, and high dissolved oxygen. Cell # 4 is also for settling dead bacteria and algae cells clarifying the water. This objective is more easily accomplished by getting the most productivity out of Cell # 1 as possible.

The Mahnomen lagoon system is producing good numbers at the time of field testing and sampling and is compliant with its permit limits,

Monitor water quality trends over time.

Figure 3. Cell # 2 of the Mahnomen Wastewater Lagoon System

Figure 4. Scott Zortman with the Mahnomen Wastewater System Testing for Ammonia and Ortho-Phosphorous

Figure 5. Cell 4 of The Mahnomen Wastewater Lagoon System

Field Testing Data Analysis

Dissolved Oxygen Concentrations

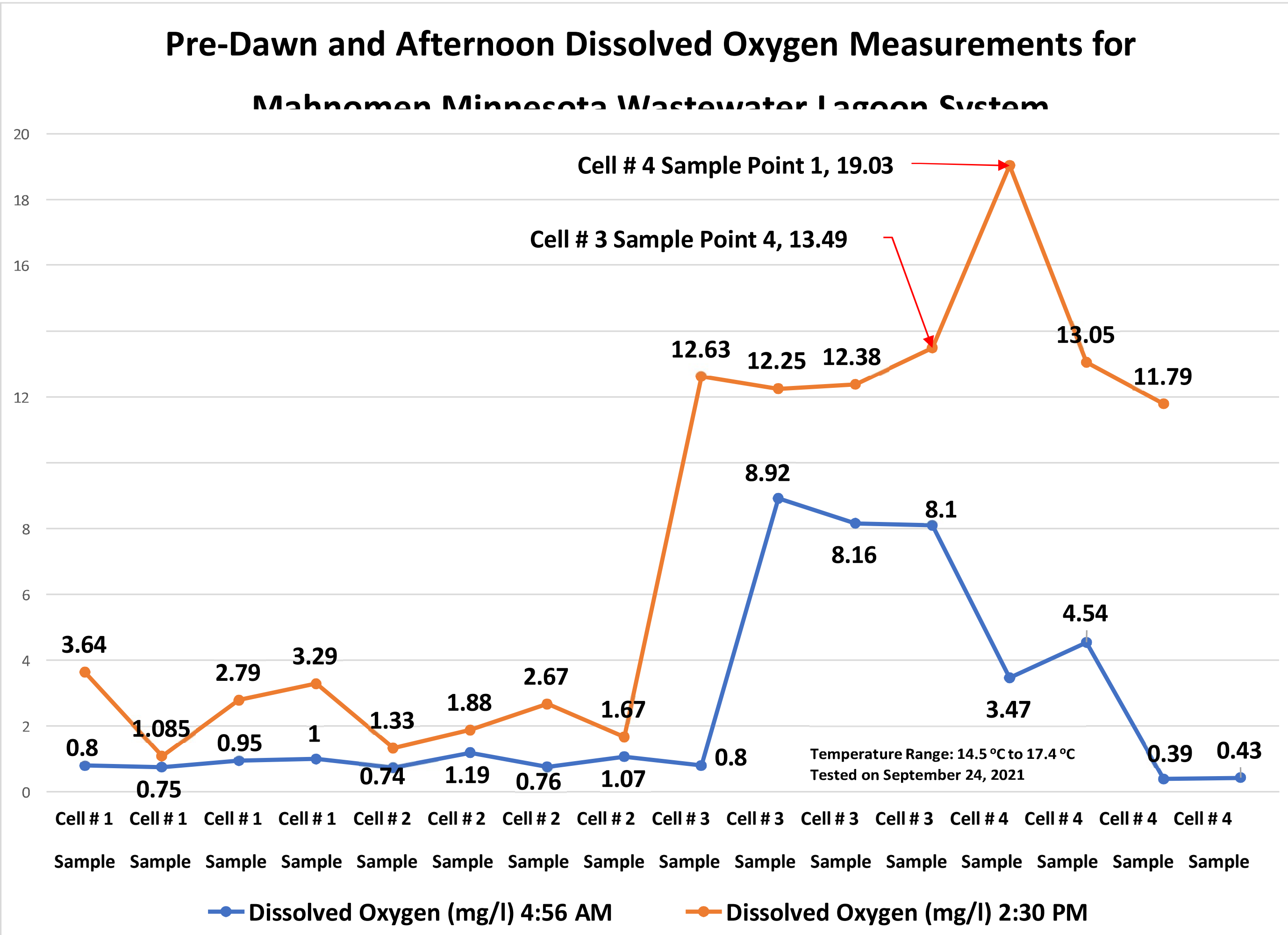


Figure 6. Predawn and Afternoon Dissolved Oxygen Concentrations.

Always keep dissolved oxygen concentrations above two (2) mg/l for greater $CBOD_5$, TSS, ammonia removal, odor control, and optimal performance.

There are two loading sources for the Mahnomen wastewater lagoon system, 1) the loading coming in daily, and 2) the sludge blanket. Nutrients are stored in the bodies of dead bacteria, algae, and protozoa that make up the sludge blanket. This sludge feeds nutrients and soluble BOD back into the water column, putting a strain on the system. This loading manifests itself in low dissolved oxygen concentrations and increasing effluent TSS, CBOD, and ammonia trends.

Low DO in Cell # 1 can be supplemented using a simple two (2) inch trash pump and recirculating water high in DO from Cell 2 or 3 to the influent of Cell # 1.

Cell # 4 DOs are low due to the shallow nature of the treatment cell at the time of testing.

Section 4 – Field Data Analysis

Dissolved Oxygen Profile Taken by Boat from the Middle of Cell # 1

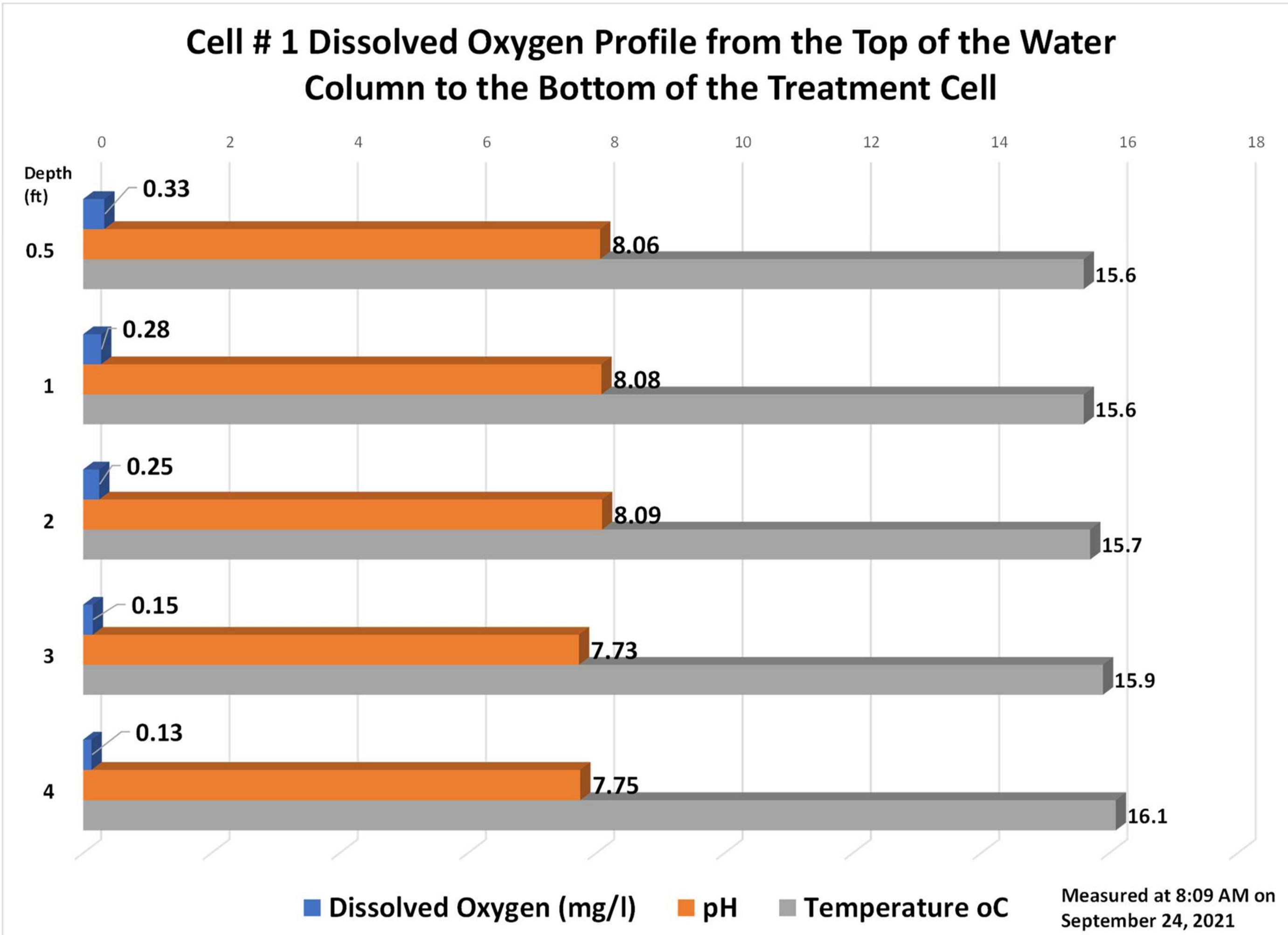


Figure 7. Cell # 1 Dissolved Oxygen Profile Taken by Boat from the Middle of the Pond

Recirculation of water from Cell # 3 to Cell # 1 can lift the DO levels in this Cell to prevent odors and provide better treatment. Let your DO and pH meter dictate when the trash pump will run. Typically, a recirculation trash pump is run from 1:00 PM to 7 PM.

Measure DO in the third (3rd) treatment cell to ensure recirculated water is over five (5) mg/l of Dissolved Oxygen. Recirculated water should be drawn from the very upper surface of the Cell. Floats are added to the suction line of the trash pump.

Section 4 – Field Data Analysis

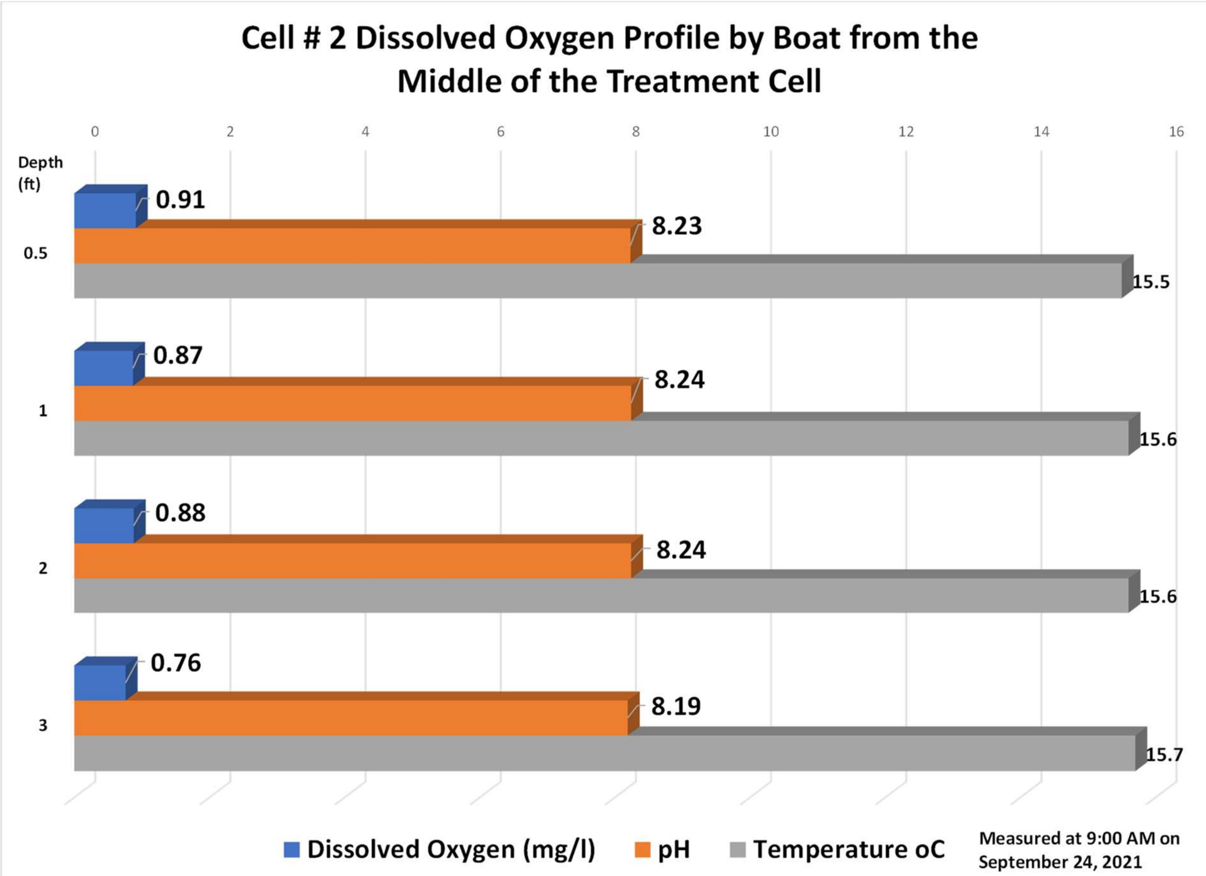


Figure 8. Morning Dissolved Oxygen Profile for Cell # 2 Taken by Boat from the Middle of the Treatment Cell

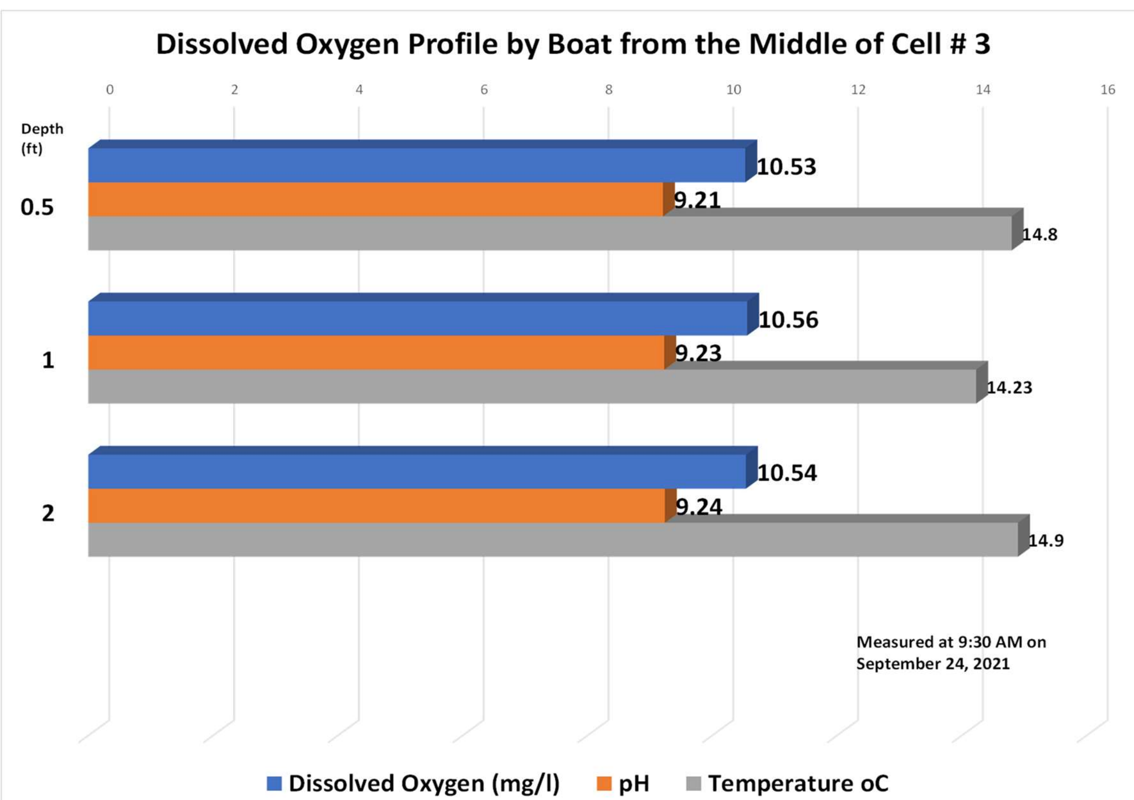


Figure 9. Cell # 3 DO Profile from the top of the Water Column to the Bottom of the Treatment Cell

Section 4 – Field Data Analysis

RMB Laboratories Intra- Pond BOD_5 Test Results

On Friday, September 24, 2021, samples were delivered to RMB Labs for intra-pond BOD_5 analysis. Below are the results.

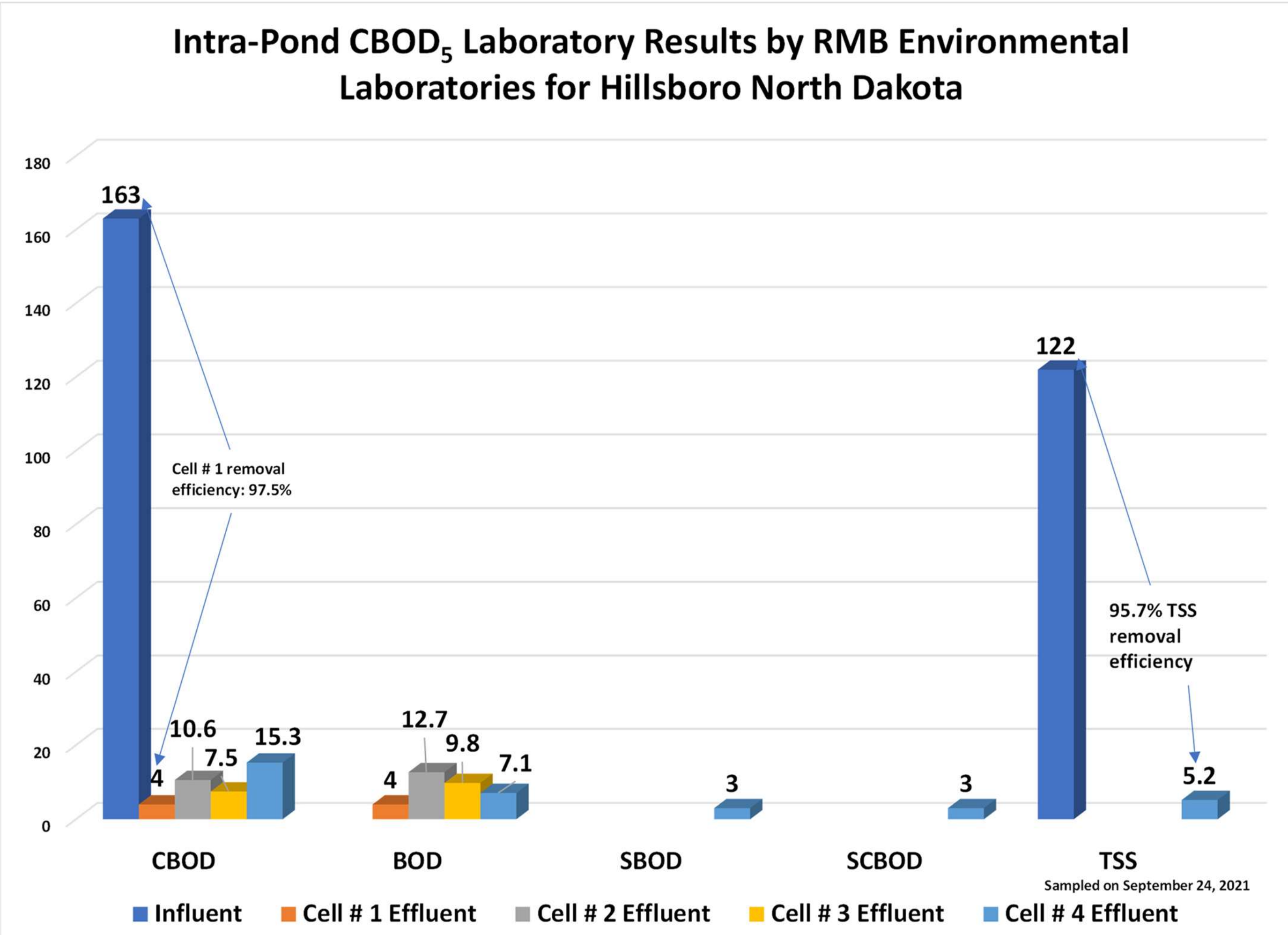


Figure 10. Intra-pond BOD_5, TSS, and Ammonia Results from RMB Labs

Benthal feedback is where the sludge feeds BOD_5, TSS, and algae growth by releasing nutrients once tied up in the cells of dead algae and bacteria that make up the sludge blanket. Notice the increase in $CBOD_5$ and BOD_5 from the Figure above. Low dissolved oxygen concentrations and an increase in $CBOD_5$ could be due to accumulated sludge.

Algae is the number one cause of BOD_5 violations in the US because algae consume oxygen for five (5) days under dark conditions in the BOD_5 test bottle and incubator. When the lights are off algae, switch to oxygen consumption. That is why the most meaningful Dissolved Oxygen test is performed during the morning before sunlight hits the pond system. The $CBOD_5$ without Algae (SBOD) is three (3) mg/l in Mahnomen. The fifteen-point-three (15.3) mg/l of TSS does not require much oxygen and significantly interferes with the effluent BOD numbers.

As mentioned earlier, the loading to the system is about at maximum for a facultative pond system in Minnesota. Adding air will be the next step if the Mahnomen population and flow increase.

Section 4 – Field Data Analysis

Field Nutrient Testing

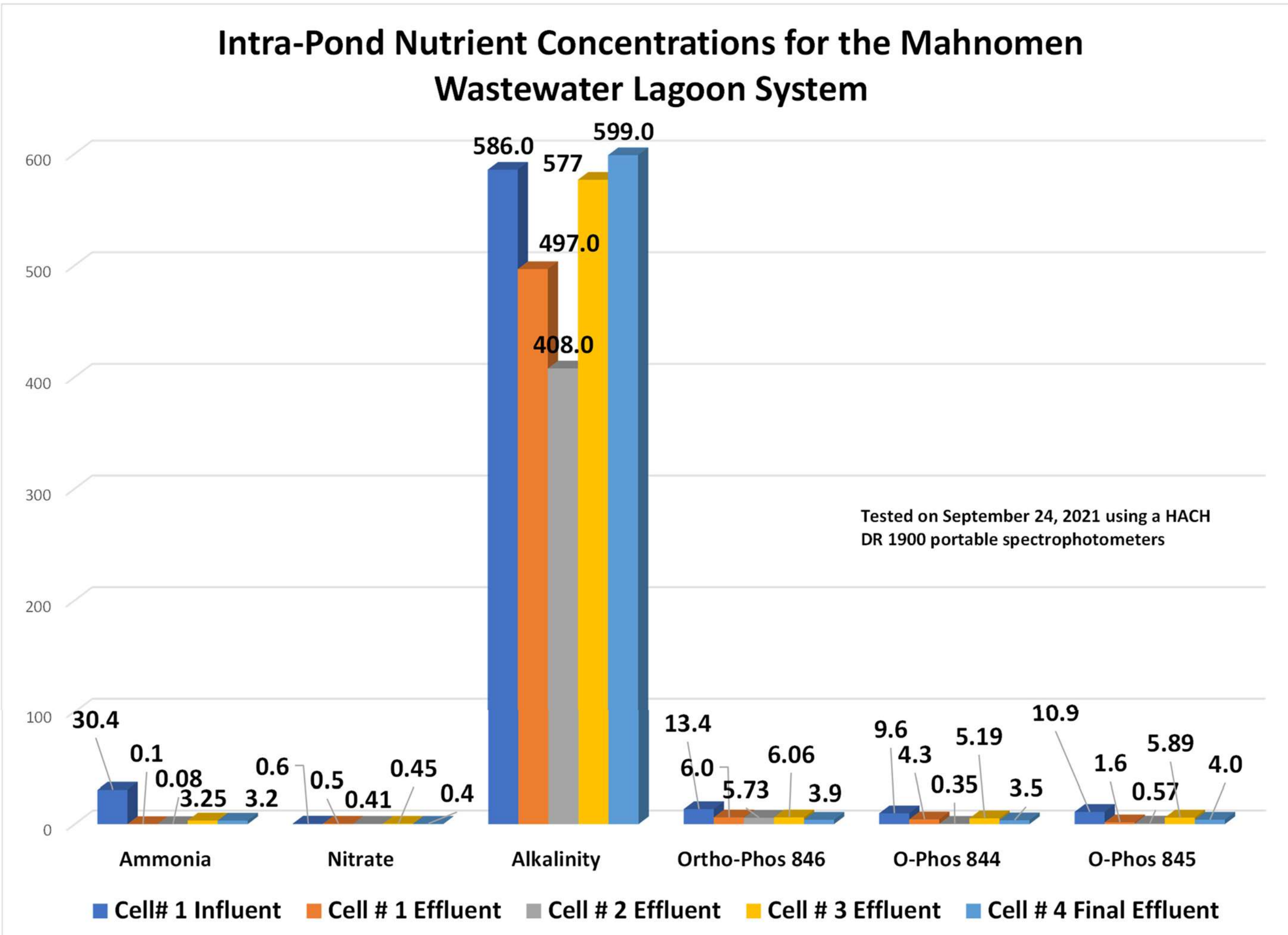


Figure 11. Intra-Pond Ammonia, Nitrate, Alkalinity, and Ortho-Phosphorous Results from Field Measurements

Ammonia removal is excellent at the effluent of Cell # 1 and # 2 but increases in Cell # 3 and 4. The primary ammonia removal pathway appears to be volatilization through high pH followed by nitrification and then microbial assimilation.

The reduction in alkalinity is the only evidence of nitrification as the measure of nitrification ($NBOD_5$) is extremely low.

$BOD_5 – CBOD_5 = NBOD_5$: The relative number of nitrifying bacteria in a system. $NBOD_5$ is the test to determine if the pond system removes ammonia through nitrification.

Section 4 – Field Data Analysis

Sludge Accumulation

Mahnomen Minnesota								
Sludge Blanket Volume and Retention Time Summary								
Item	Units	**Cell # 1**	**Cell # 2**	**(1/2) Cell # 2A**	**Cell # 3**	**Cell # 4**	**(1/2) Cell # 4**	**Totals**
Bottom Length	feet	**1178**	**937**	**689**	**872**	**840**	**330**	
Bottom Width	feet	**537**	**689**	**332**	**865**	**330**	**155**	
Side Slopes	1 to	**3**	**3**	**3**	**3**	**3**	**3**	
Average Sludge Depth	feet	**0.57**	**0.58**	**0.58**	**0.8**	**0.6**	**0.6**	
As-Built Bottom Elevation	feet	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
As-Built Top-of-Bank Elevation	feet	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	
Bottom Area	sq ft	632,586	645,593	228,748	754,280	277,200	51,150	
Top of Sludge Length	feet	1181.42	940.48	692.48	876.8	843.6	333.6	
Top of Sludge Width	feet	540.42	692.48	335.48	869.8	333.6	158.6	
Top of Sludge Area	sq ft	638,463	651,264	232,313	762,641	281,425	52,909	
Sludge Volume	cu ft	362,249	376,088	133,708	606,768	167,587	31,218	1,478,813
Sludge Volume	**gallons**	**2,709,622**	**2,813,141**	**(500,068)**	**4,538,627**	**1,253,554**	**(116,755)**	**10,698,122**
Embankment Height	feet	7.00	7.00	7.00	7.00	7.00	7.00	
Freeboard Required	feet	**2**	**2**	**2**	**2**	**2**	**2**	
Useable Lagoon Depth / Remaining Water Cap after Sludge	**feet**	**2.82**	**2.46**	**2.46**	**2.18**	**2.40**	**2.40**	
Top of Water Max Length	feet	1198	950	707	892	860	350	
Top of Water Max Width	feet	557	707	350	885	350	175	
Top of Water Max Area	sq ft	667,286	671,650	247,450	789,420	301,000	61,250	
Lagoon Volume	cu ft	1,832,820	1,620,209	585,724	1,682,633	693,840	134,880	5,721,385
Usable Lagoon Volume at Current Operating Depths with Sludge	**gallons**	**13,709,490**	**12,119,162**	**(2,190,606)**	**12,586,095**	**5,189,923**	**(504,451)**	**40,909,614**
AVE Daily Flow: 0.237 MGD (DMR)								
Actual Retention Time Based on Sludge Volume, Actual Operating Depths, (Remaining Water Cap / Capacity)	days	**57.85**	**51.14**	**-9.24**	**53.11**	**21.90**	**-2.13**	**172.61**
Notes & Cautions:								
Elevations are estimates from field measurements								
Dimensions are from Google Earth								
Treatment Cell bottoms were uneven.								
Rounded corners exist, square corners are used in the calculations above								
Averages of water depths and average sludge blanket thickness are used								
Slopes are assumed at 3:1								
Flow is a 6 year average from DEQ Records on US EPA ECHOI Database.								

Figure 12. Sludge Blanket Volume and Retention Time Calculations.

Section 4 – Field Data Analysis

H&S used a survey level rod to measure the water depth at twenty (20) sample points in the lagoon. At the same time, an infrared sludge level detector was used to detect the top of the sludge blanket. Excel calculated the difference between the top of the water and the top of the sludge, effectively measuring sludge blanket thickness.

H&S Environmental, LLC reports 10,689,122 gallons of sludge in Cells 1, 2, and 3. Cell # 4 could not be accessed for profiling due to the shallow water cap over the sludge. When water levels return to normal, Cell # 4 should be sludge judged.

Aside from occupying valuable capacity and lowering a treatment cell's retention time, sludge releases nutrients and soluble BOD back into the water column. These nutrients feed TSS production through algae growth. Because they consume oxygen under the dark conditions of the BOD_5 test, algae can result in high BOD_5. The release of nutrients from sludge feeds algae growth resulting in TSS permit violations.

Once sludge reaches about eighteen (18) inches in thickness, it is time to consider removal to prevent nutrient feedback causing problems with increases in algae growth leading to TSS problems.

Sludge removal options include dredging, pressing or centrifuging, and hauling off-site, as well as removing in situ with chemical oxidizing agents. Each method has its place. Sludge can also be pumped out and applied to a Geo-Tube or drying bed to dry on-site for two (2) years. Drying on-site allows for the removal of the water, reducing tipping fees and hauling costs. When dredging or drying, and scraping, the treatment cell must typically be taken offline.

Dredging mixes a treatment cell releasing Ammonia, Nitrates, phosphate, and CO2 to stimulate algae and bacteria growth. The filtrate from a belt press will concentrate nutrients as it squeezes sludge, creating a stream of nutrient-rich water that will load the plant. This nutrient-rich filtrate stream will, in most cases, cause a crash in DO and create odors. Be aware of the centrate or filtrate coming off the centrifuge, press, or weepage from a Geo-tube or runoff from a drying bed. Add air to the remaining working treatment cells when desludging. Keeping air above two (2) mg/l will keep odors and nutrient loading to a minimum.

If time permitted, mixing the sludge blanket and adding agricultural stubble breakdown chemistries can remove several feet of sludge over time. Mixing and chemical agents will not remove sand grit or gravel and leave dead bacteria bodies (Humus). The disadvantage of treating in place by mixing and adding is that you run the risk of freeing Ammonia, Nitrate, phosphate, CO_2, and organic acids to feed an algae bloom. Consult an expert before mixing a treatment cell. There are proven chemical additives from the agricultural industry that can accelerate sludge removal on-site associated with mixing.

Aeration and Dissolved Oxygen

There are seven (7) indicators that the dissolved oxygen levels in the Mahnomen Minnesota pond system are too low:

1) Poor BOD_5 removal efficiency
2) Low ammonia removal efficiency
3) Odors
4) Popping sludge in the treatment Cells
5) *Daphnia* turned red in the treatment Cells
6) Low DO measurements both day **and** night. The best, most meaningful time to measure DO is before sunrise before algae have had the chance to produce dissolved oxygen

Section 4 – Field Data Analysis

7) Increasing trends in effluent BOD_5 after all the Cells have been desludged

Dissolved oxygen measurements taken at the surface may not tell the whole story. While the surface water may appear to have sufficient DO, it may be anoxic just below the surface, beginning two to three feet below the surface. Measuring Dissolved Oxygen by boat in the middle of a treatment cell from the surface to the bottom at the sludge water interface is the best way to perform a DO profile. This type of DO profile is also best performed at or before sunrise.

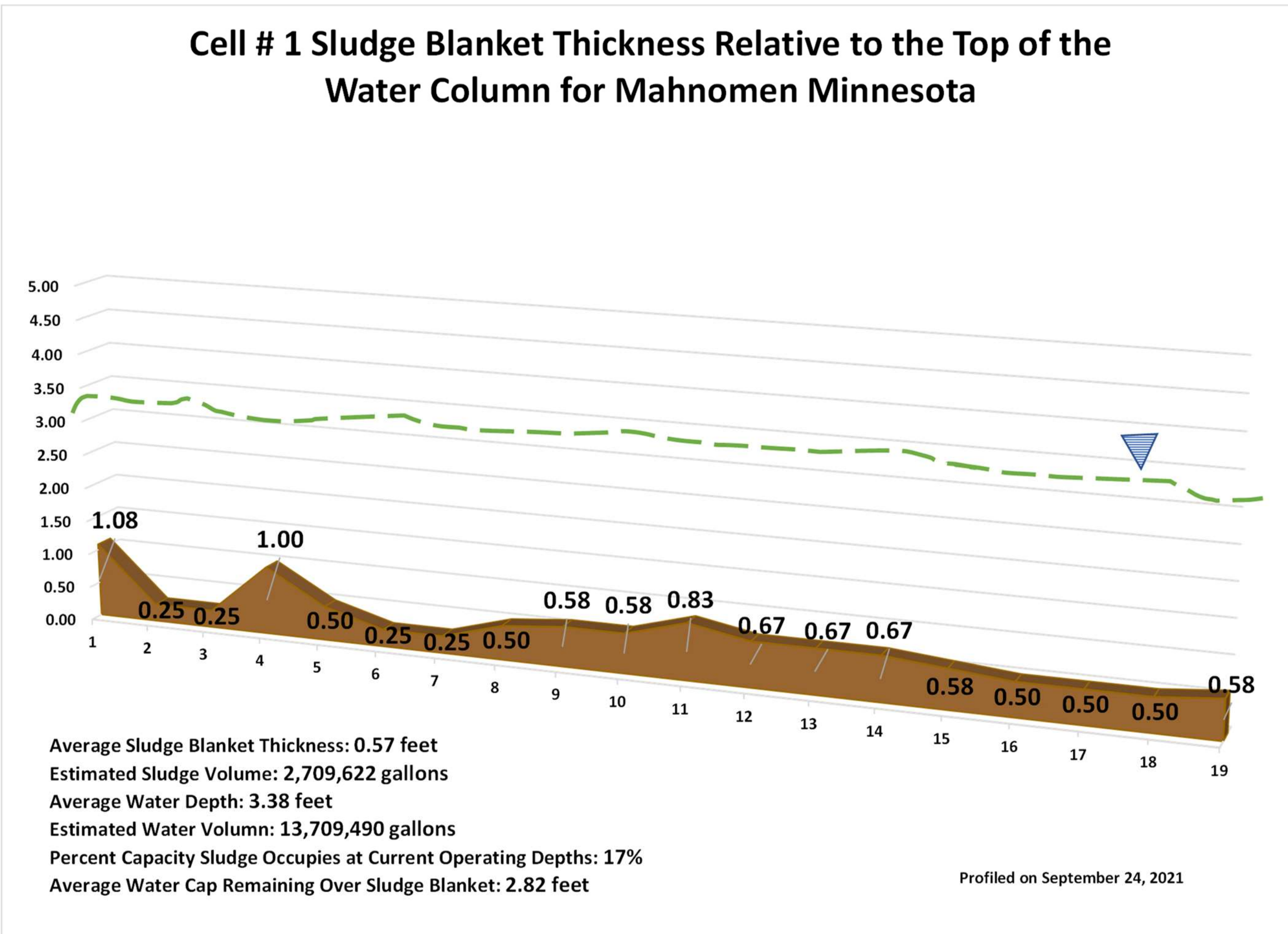


Figure 13. Cell # 1 Sludge Thickness and Volume

Section 4 – Field Data Analysis-Continued

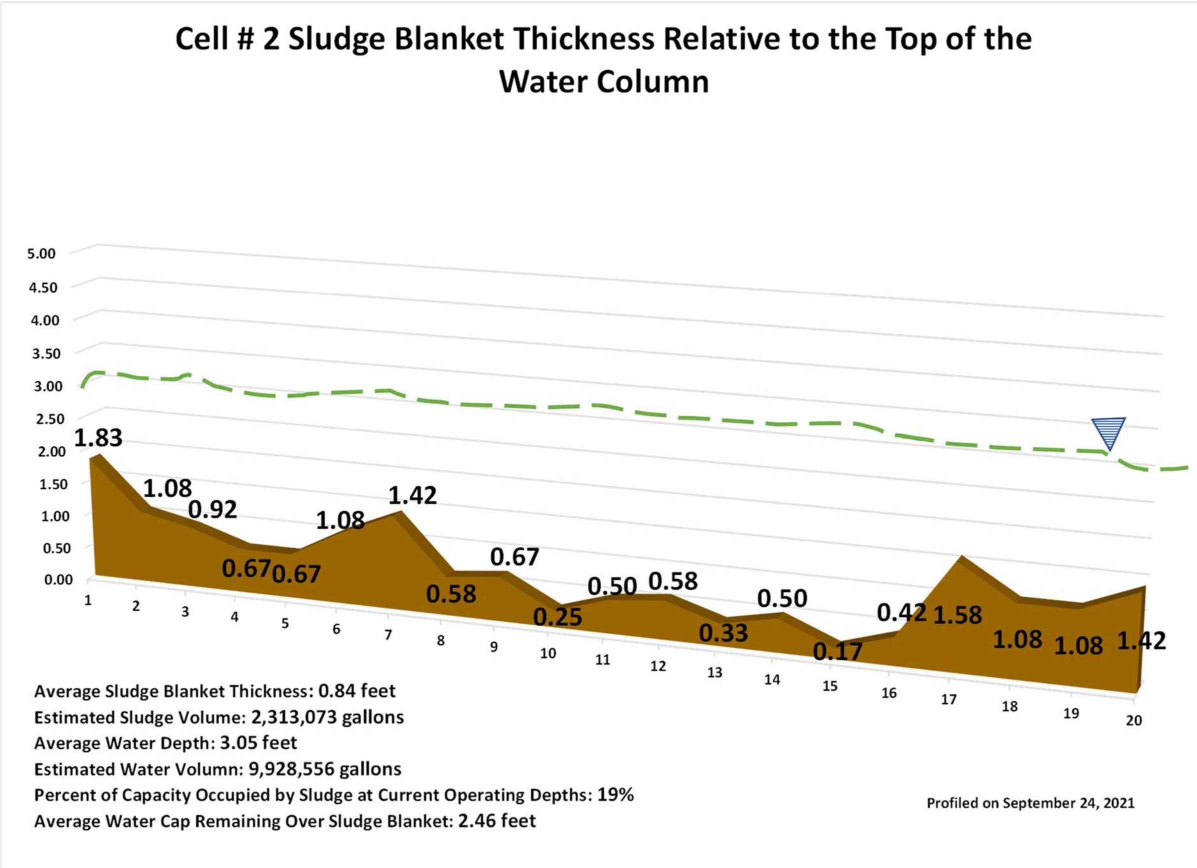


Figure 14. Cell # 2 Sludge Blanket Profile Relative to the Top of the Water

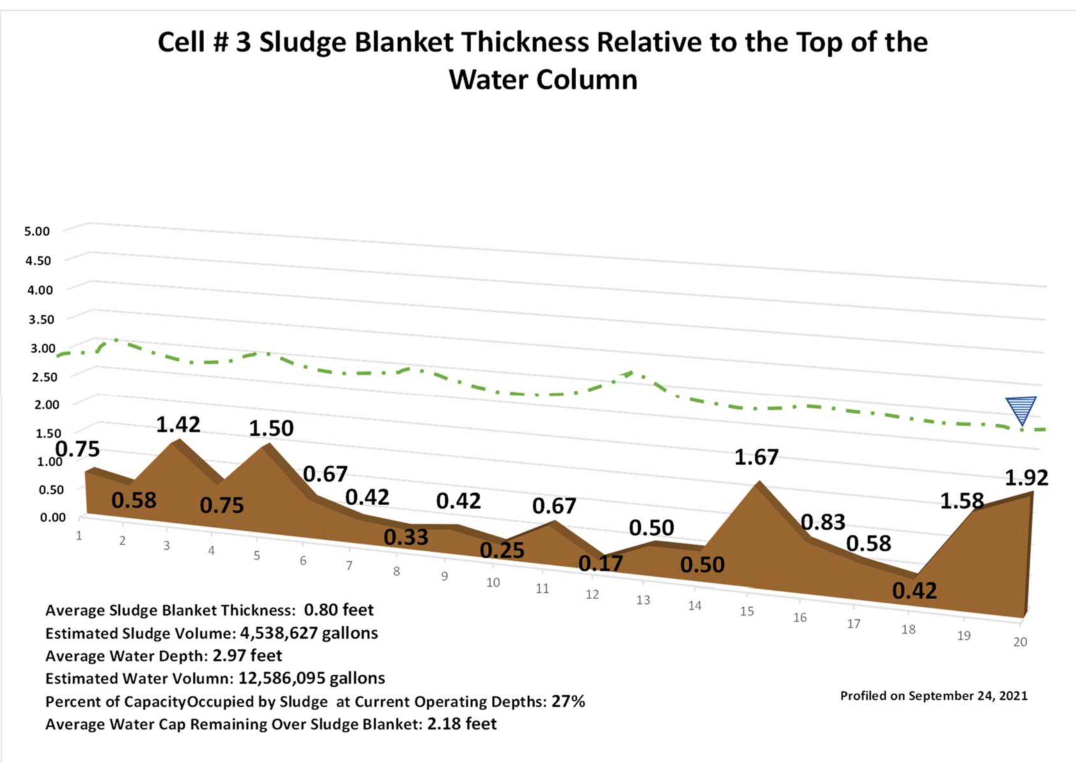


Figure 15. Cell # 3 Sludge Blanket Thickness Relative to the Top of the Water

Section 4 – Field Data Analysis Cont-

Sludge has a powerful impact on the effluent water quality of lagoon systems and should not be allowed to accumulate past eighteen (18) inches. Because it is so expensive to remove, the City of Mahnomen should begin to save for the inevitability of desludging.

Lagoons fail for two (2) main reasons; 1) Poor hydraulic design (short-circuiting) and 2) Sludge accumulation.

Short-circuiting is the worst thing that can happen to a lagoon system short of someone dumping toxic waste in the system. Sludge is the second worst thing that can affect effluent quality. Sludge stores the nutrients once assimilated and then releases them back to the water column as the dead algae and bacteria cells lyse.

Algae growth cause CBOD problems by consuming oxygen, not making it, when the lights are off. For five (5) days, a sample sits in a BOD_5 test bottle under dark conditions, and algae consume oxygen over those five (5) days inflating the BOD_5 test result. Sludge feeds algae growth, and algae growth leads to TSS violations and BOD problems because of this.

In the New England States, there is a mandate to remove sludge after it reaches eighteen (18) inches in thickness because of the problems it creates.

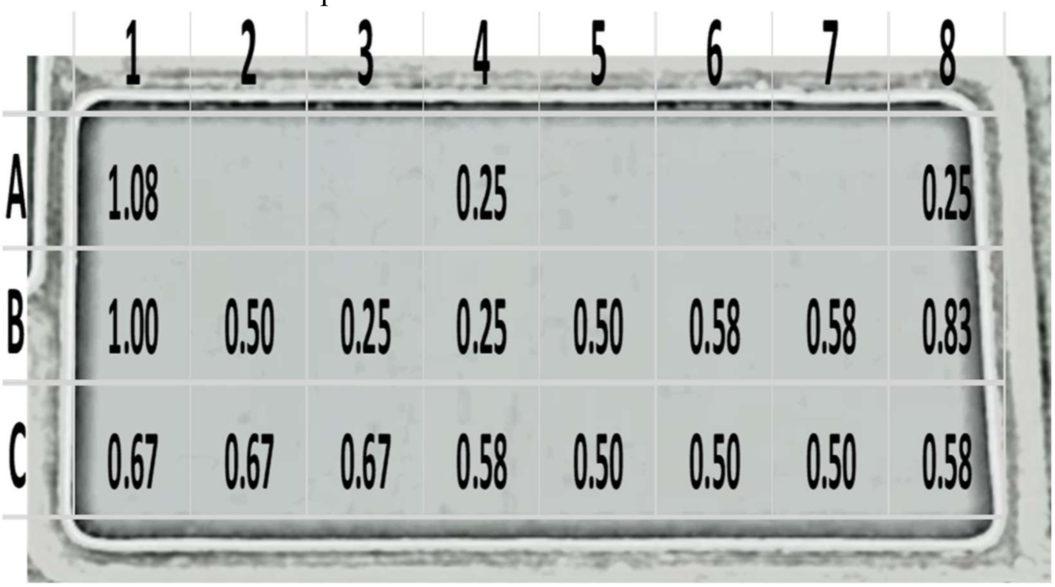


Figure 16. Sludge Blanket Thickness Locations for Cell # 1

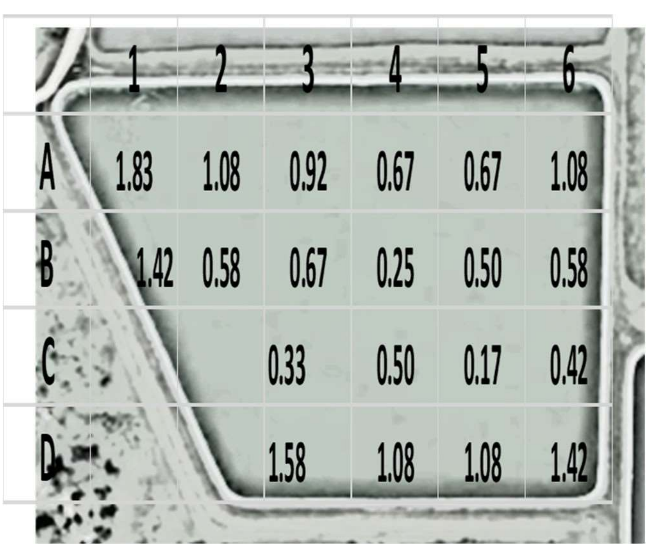


Figure 17. Cell # 2 Sludge Blanket Thickness Locations

Section 4 – Field Data Analysis Cont-

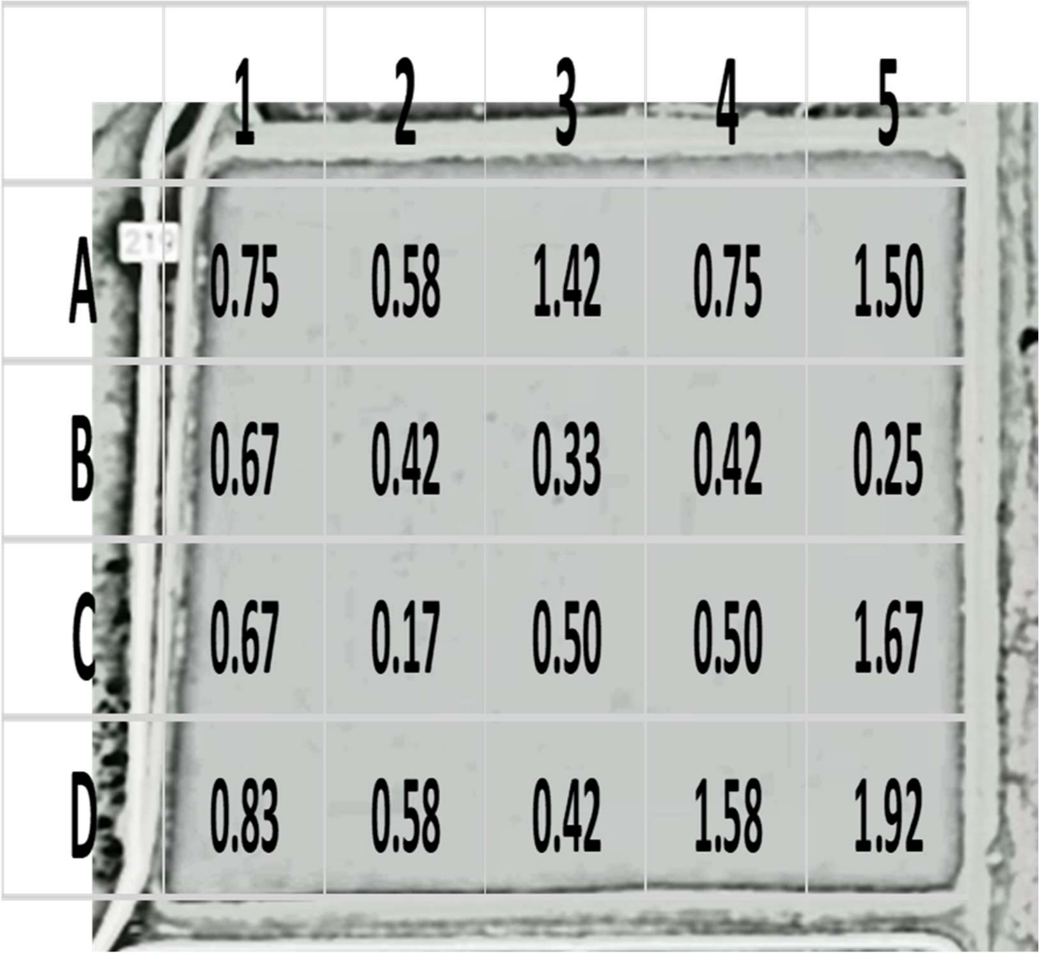


Figure 18. Cell # 3 Sludge Blanket Thickness Locations

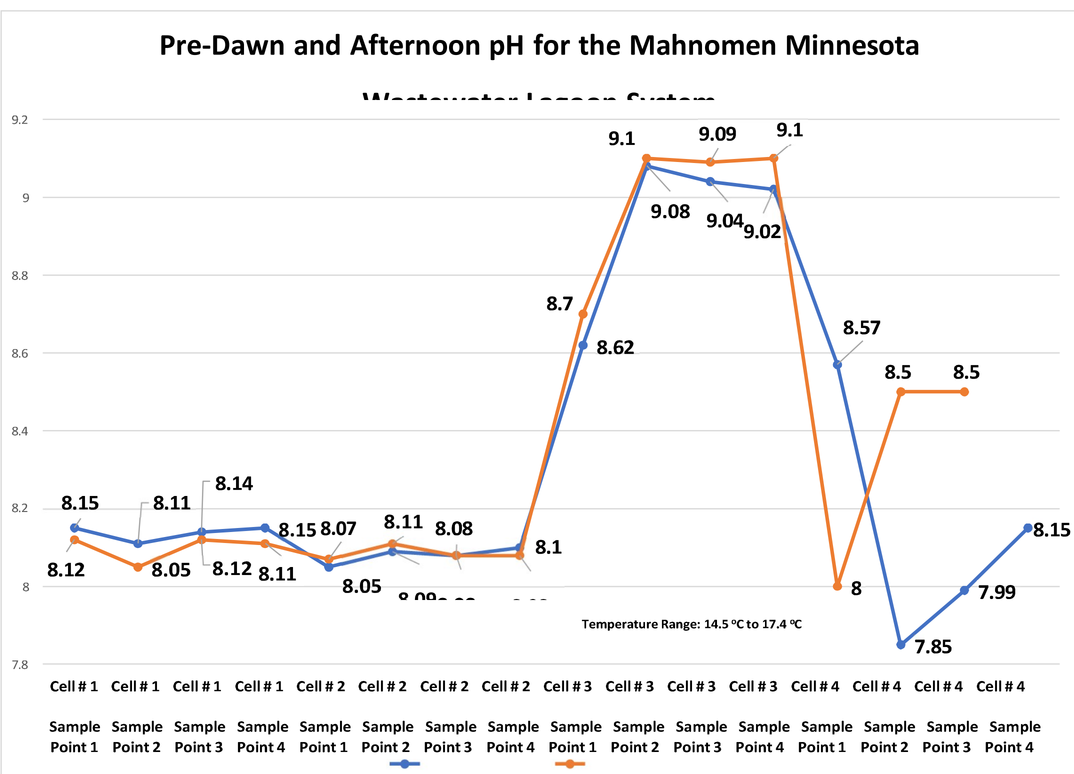


Figure 4. AM and PM pH

Section 73 – DMR Data Analysis

Influent and effluent data for Mahnomen was taken from a six (6) year search of the Minnesota Pollution Control Agencies' Wastewater Data Browser.

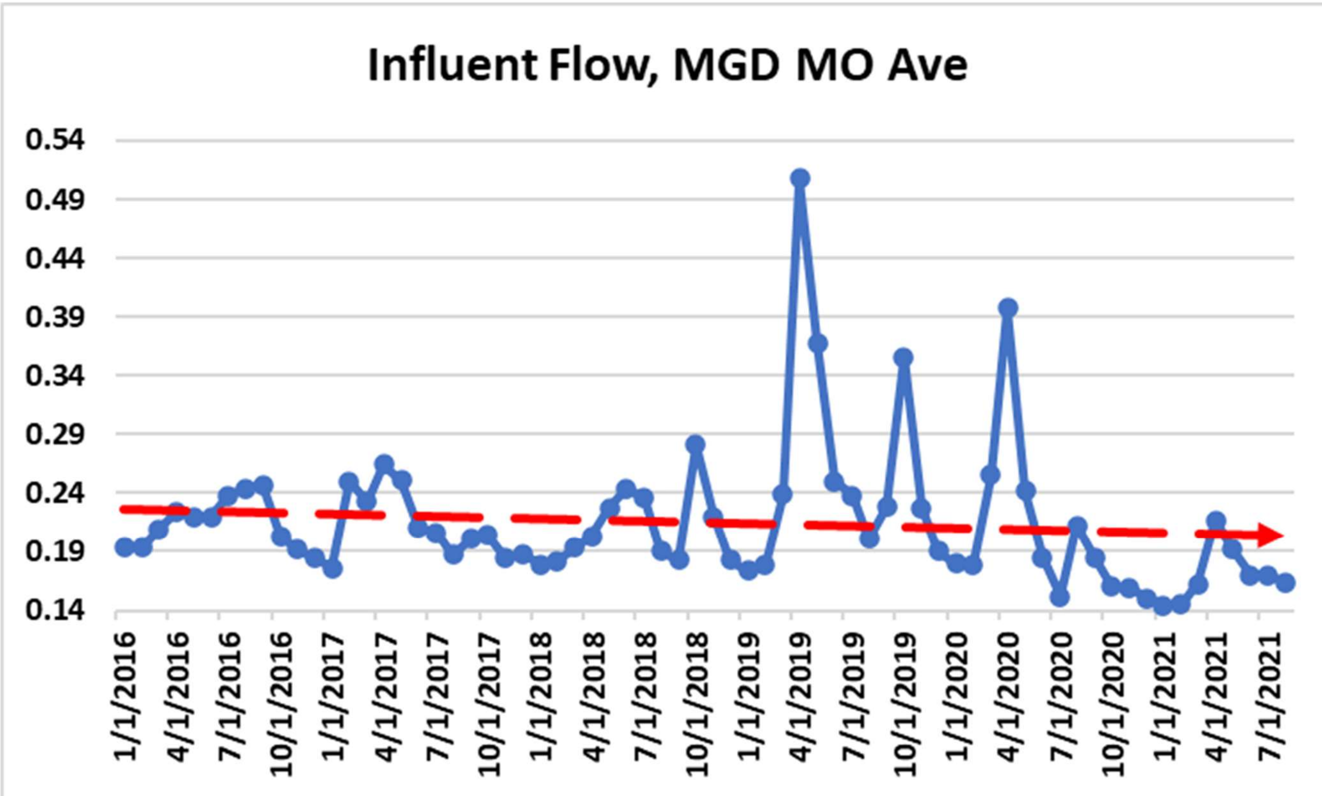


Figure 20. Influent Flows from January 2016 to August 2021. From the MNPCA Wastewater Data Browser

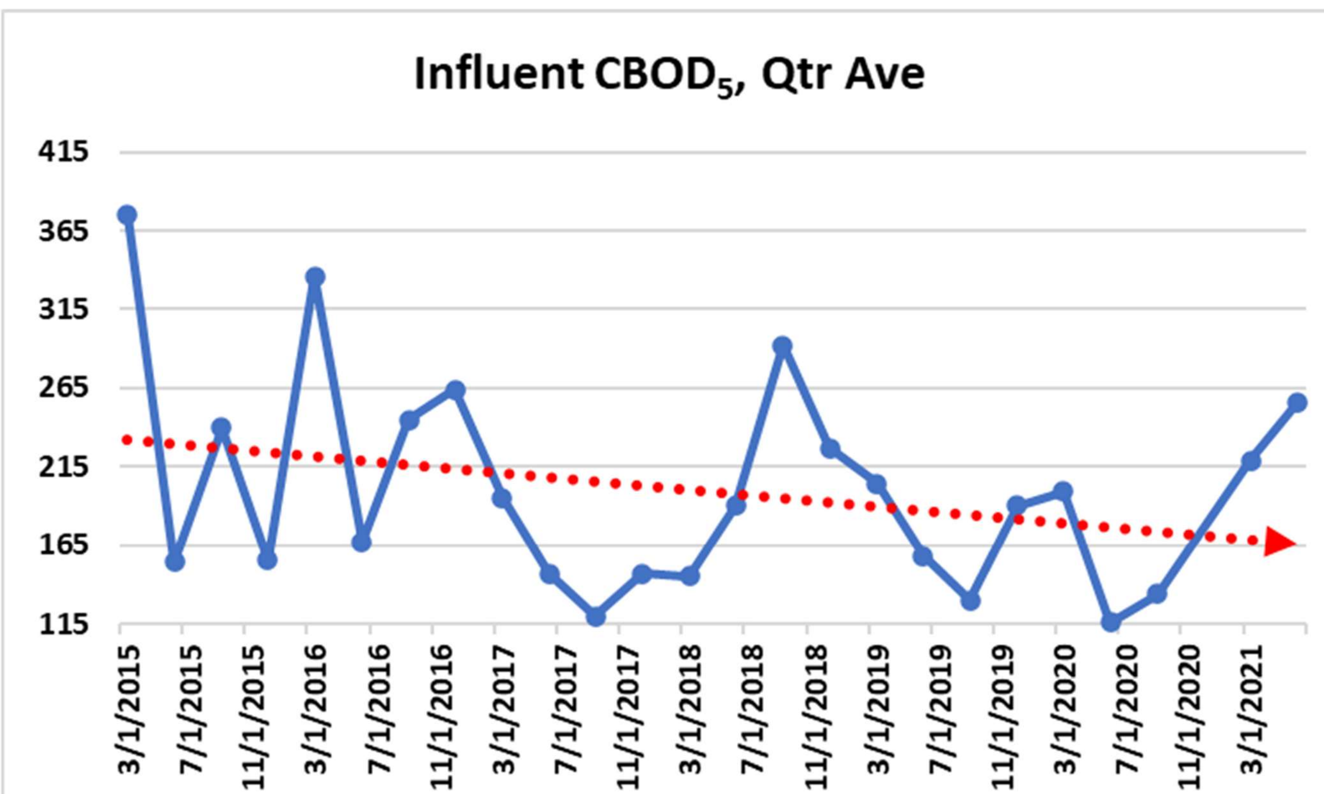


Figure 21. Influent $CBOD_5$

Section 4 – DMR Data Analysis Cont-

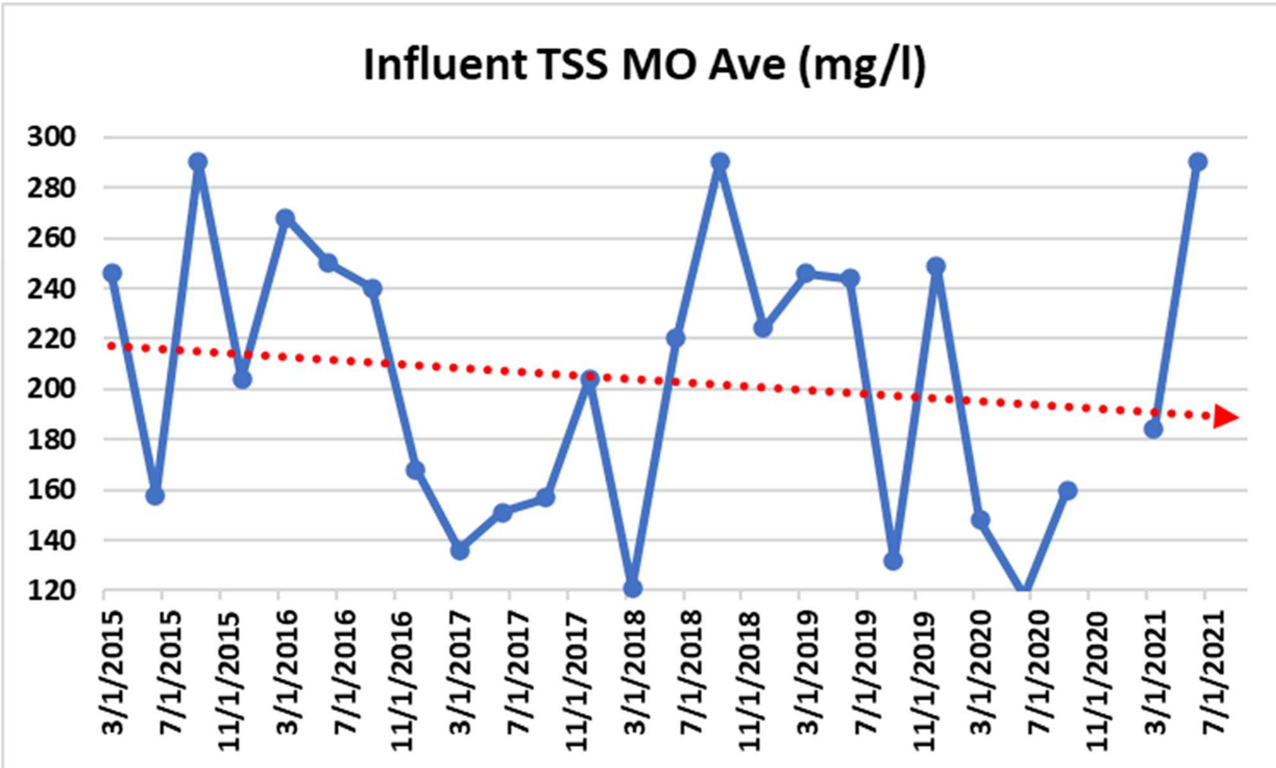


Figure 22. Influent TSS Trending Downward

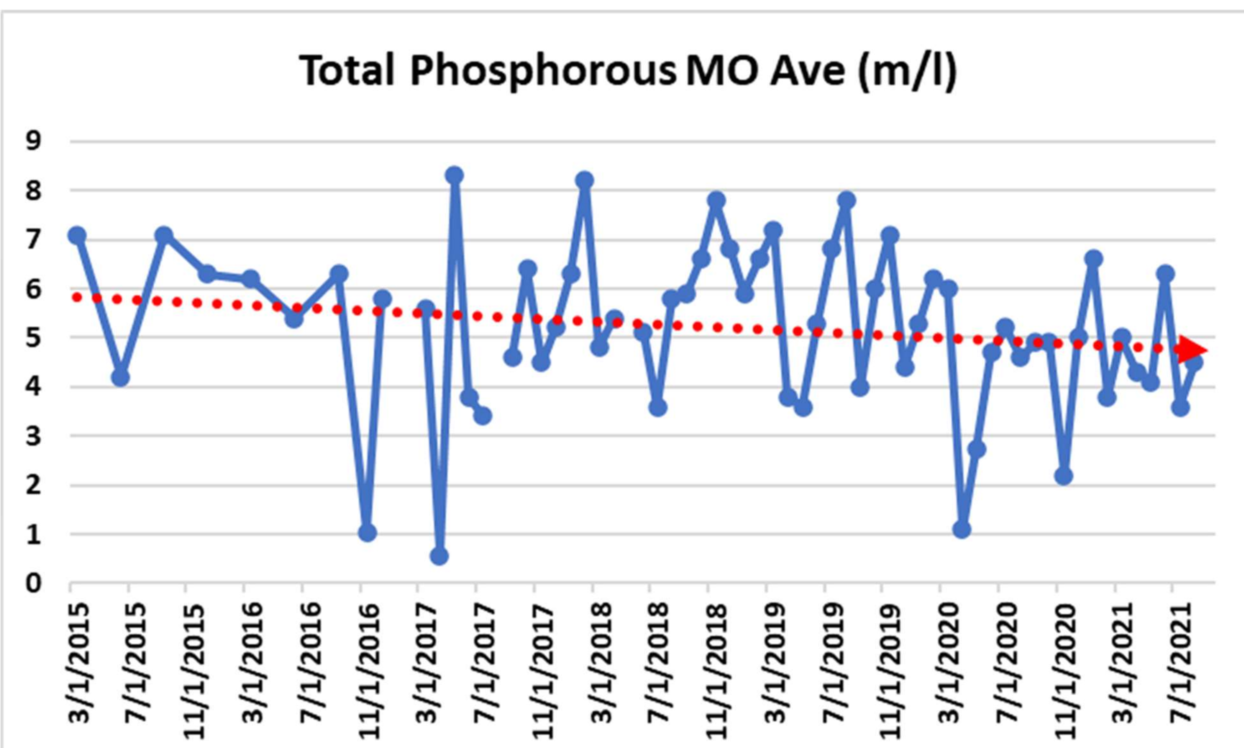


Figure 23. Influent Total Phosphorous Trending Downward

Section 4 – DMR Data Analysis Cont-

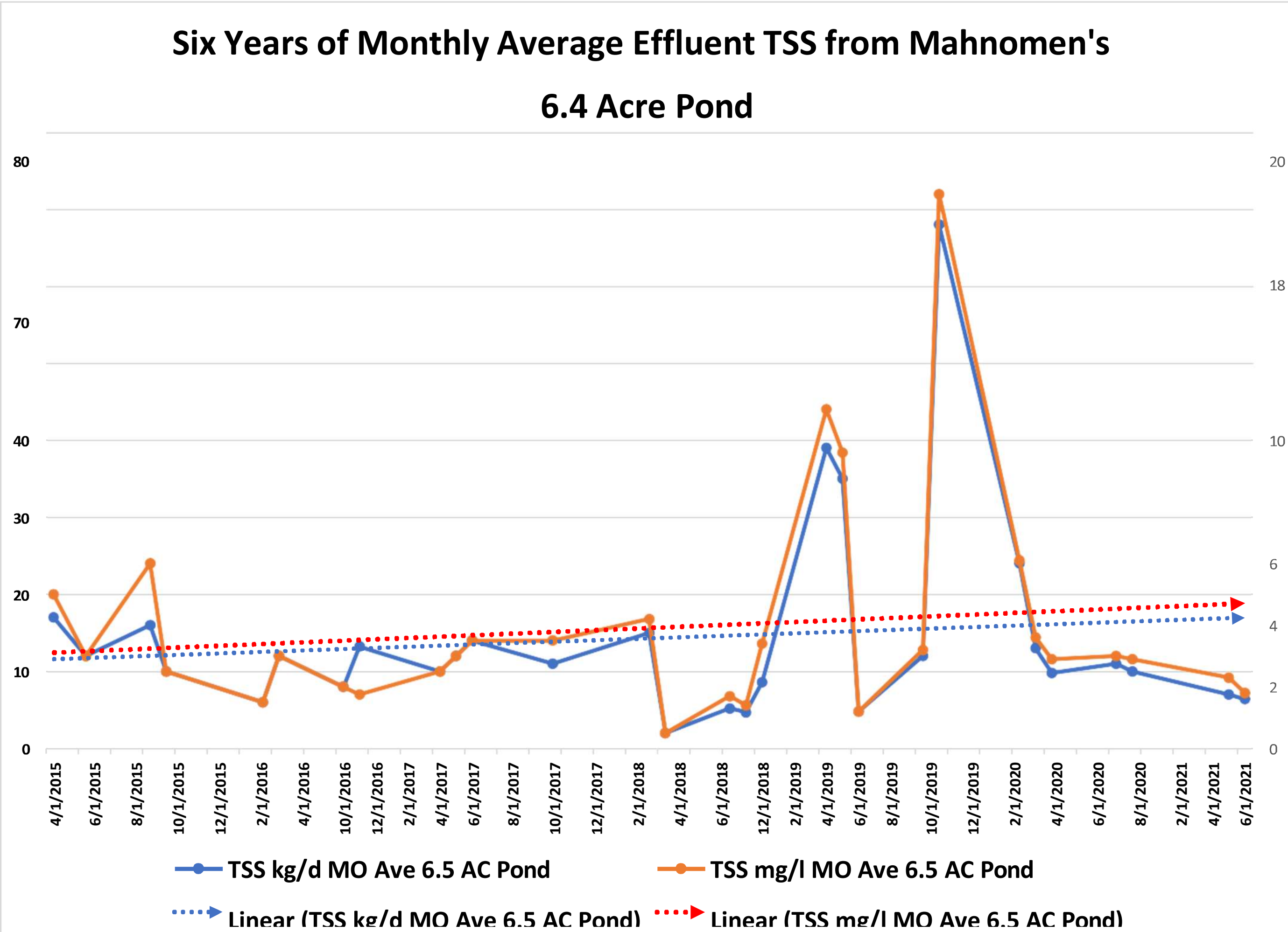


Figure 24. Mass and Concentration of the Effluent TSS for Mahnomen

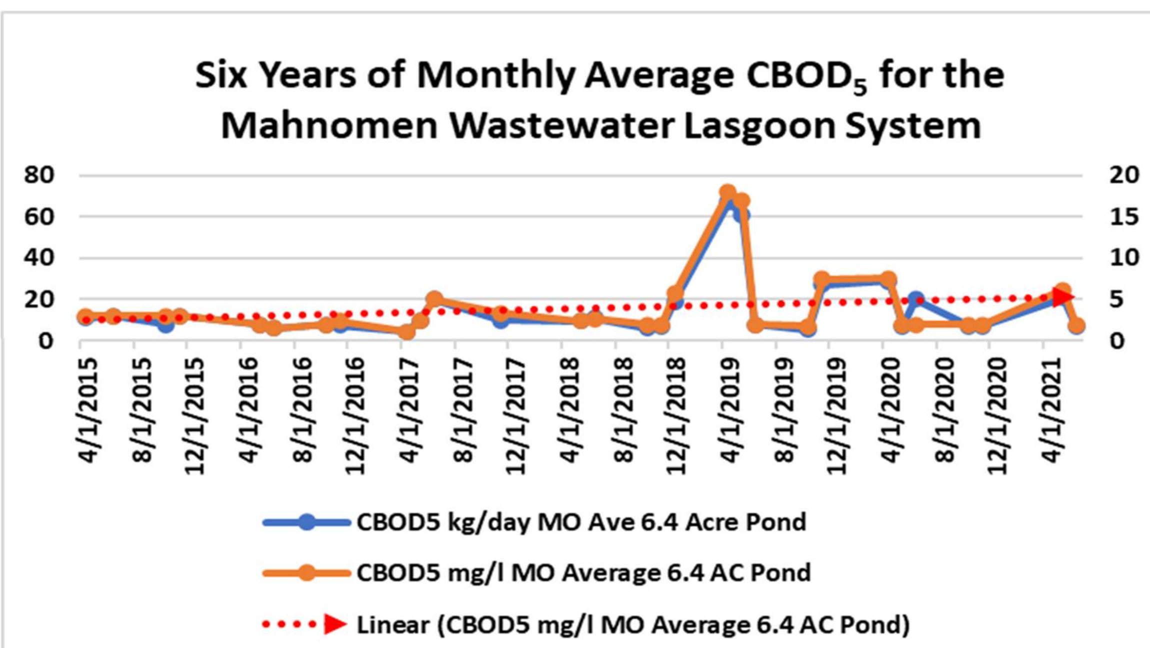
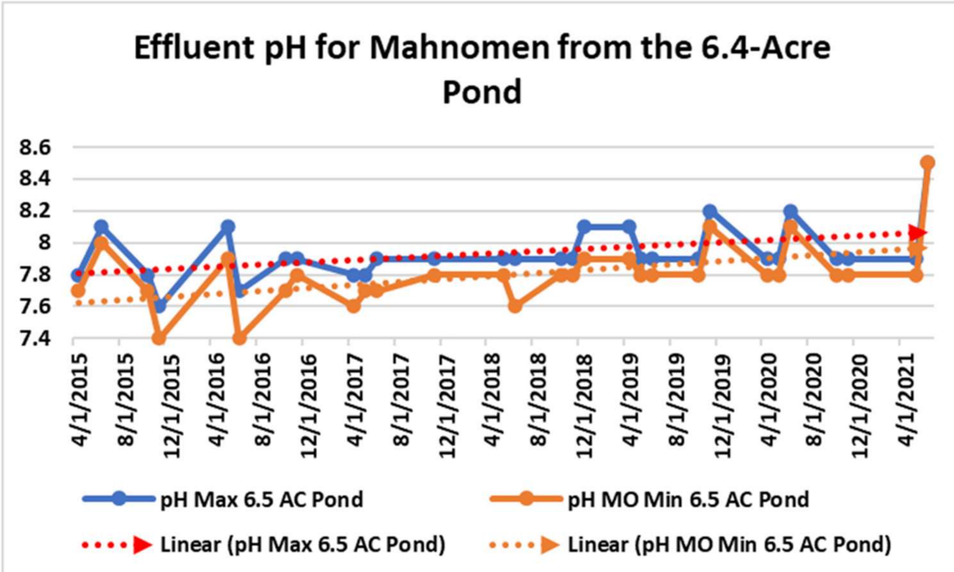
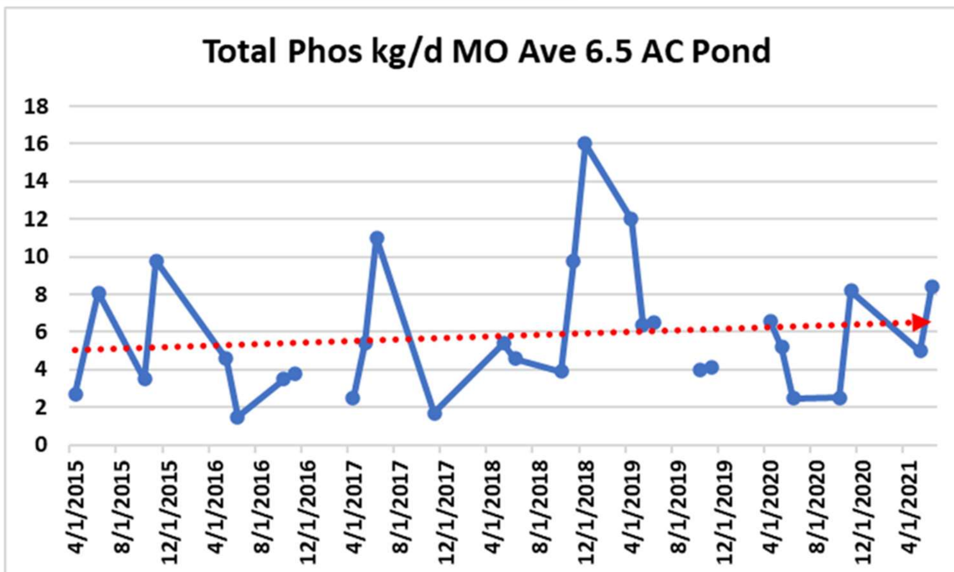


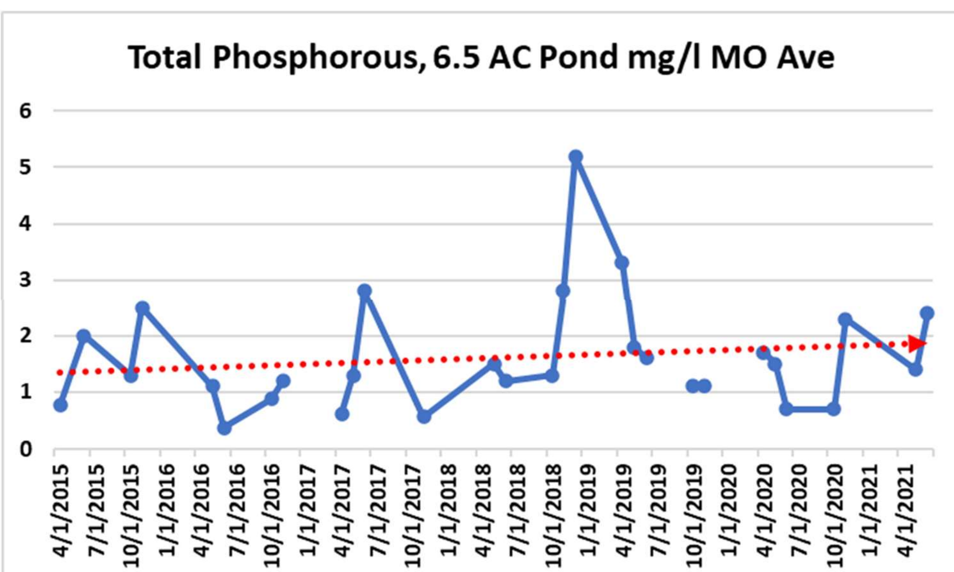
Figure 25. Six Years of Effluent $CBOD_5$ for Mahnomen

Section 4 – DMR Data Analysis Cont-



Figures 26, 27, & 28 for effluent pH and Total Phosphorous from





Section 4 – DMR Data Analysis Cont-

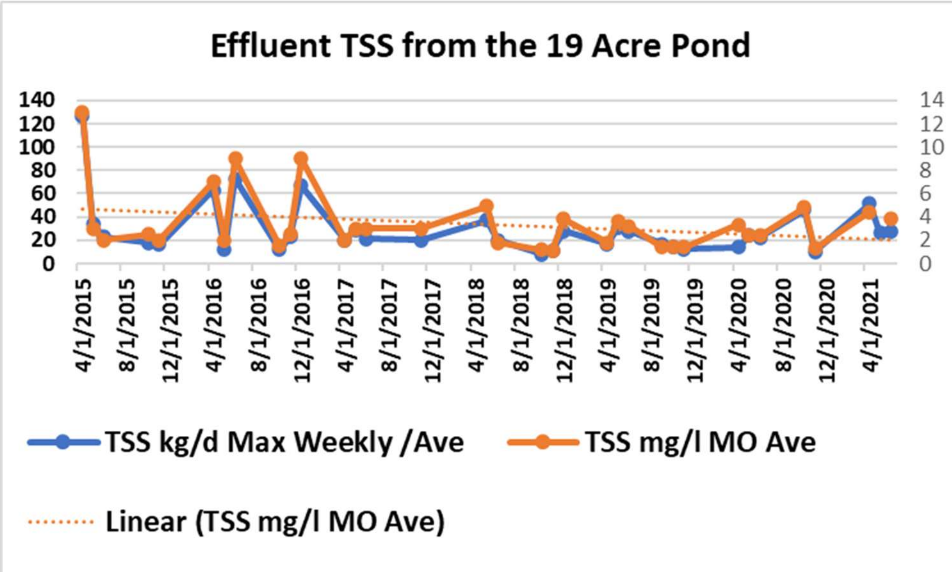
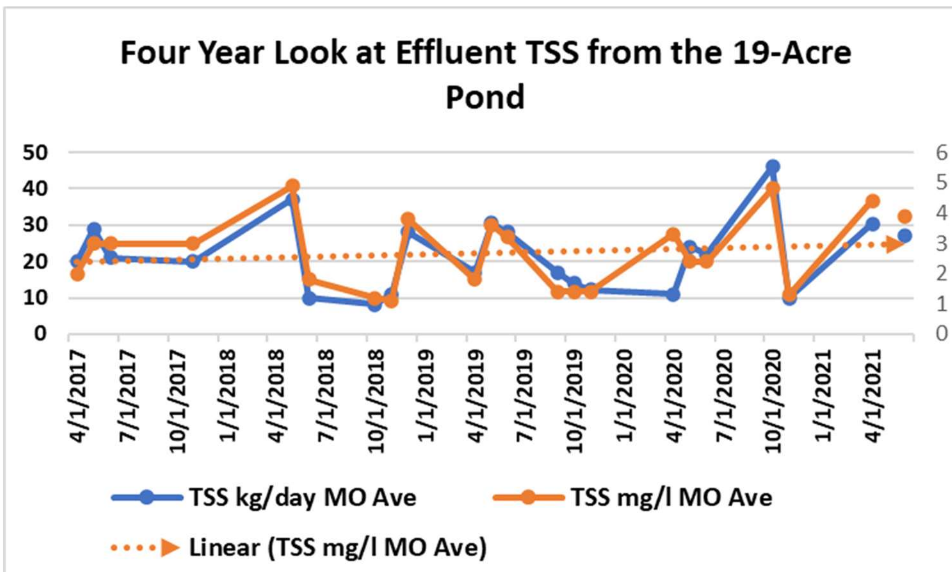
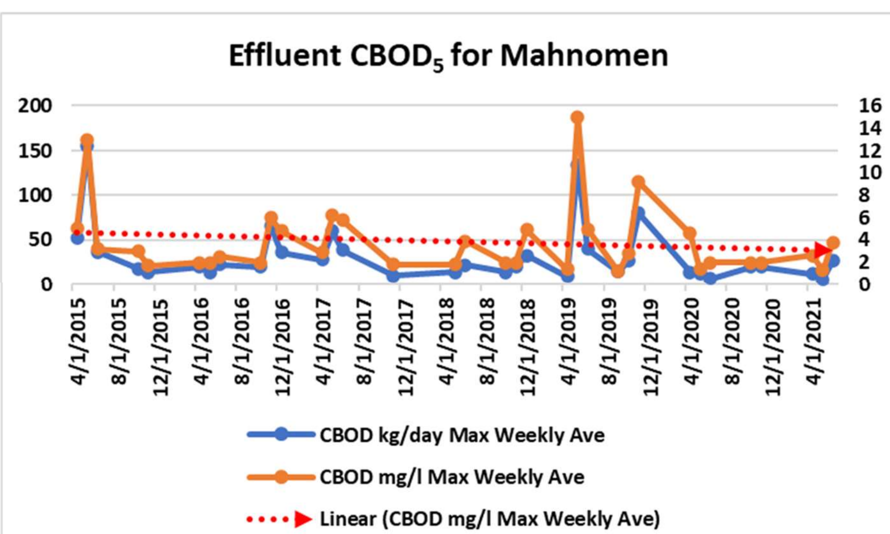


Figure 29, 30, 31, Effluent TSS and $CBOD_5$ for the 19-Acre Pond





Section 4 – DMR Data Analysis Cont-

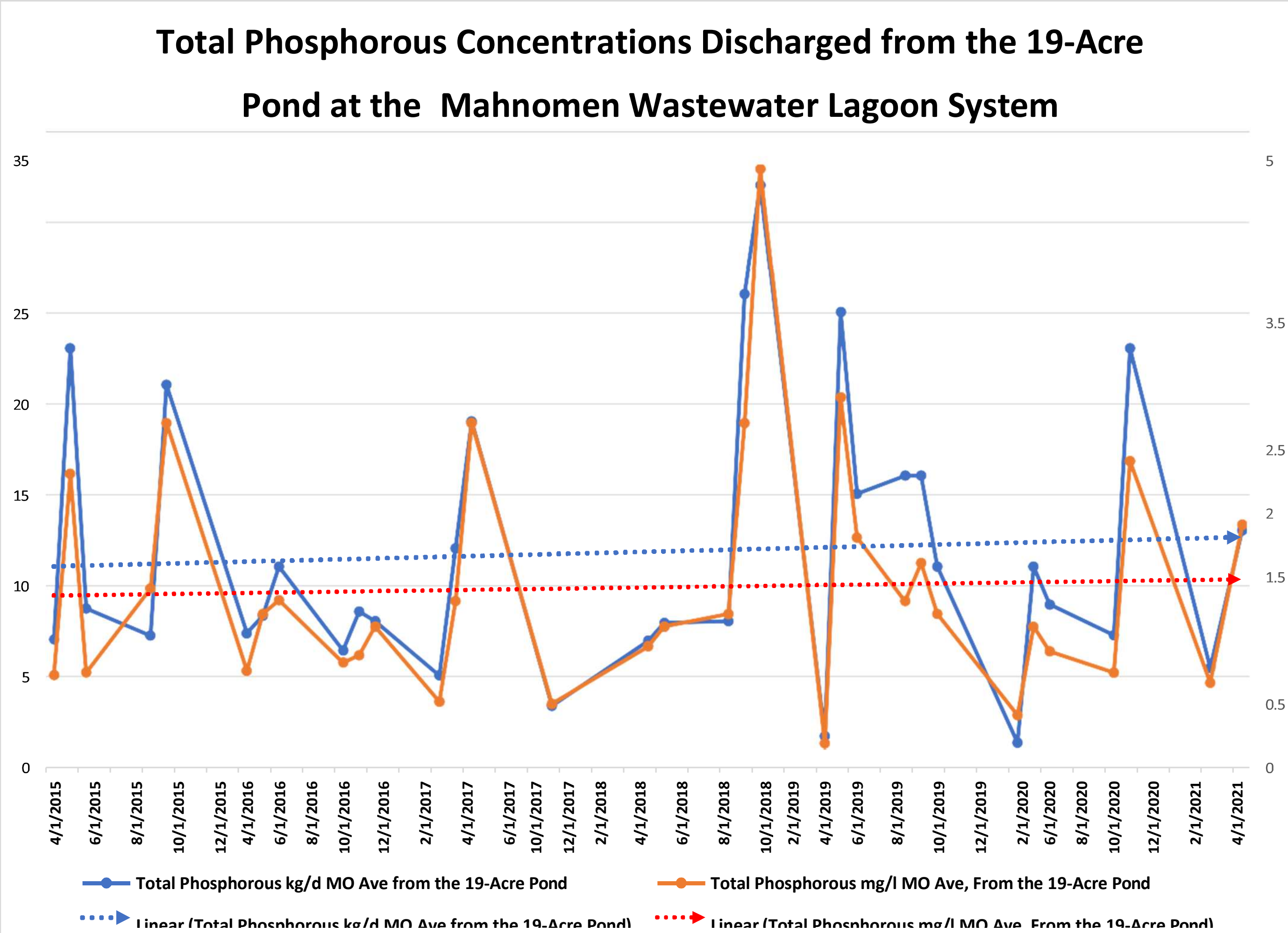


Figure 32. 19-Acre Pond Total Phosphorous

Section 5 – Summary

The Mahnomen Minnesota wastewater pond system typically meets permit limits because it holds water long enough to exhaust the nutrients that cause permit limit violations.

At the time of field testing, all limits were within permitted limitations.

Monitor effluent numbers and remove the sludge when DMR numbers get close to permit limitations.

Recirculating highly oxygenated water from Cell # 3 in the afternoons to Cell # 1 would help keep the system odor-free and improve water quality overall. Sludge judge again in three (3) years.

Section 6 – Action Items

The recommendations outlined in this report offer solutions for meeting permit limits in a long-term sustainable fashion.

Four (4) Action Items are recommended for the Mahnomen Minnesota wastewater lagoon system, and they are:

1) Re-sludge judge the system again in three (3) years. Begin with Cell # 4.
2) Closely monitor the trends in water quality permit parameters. When they get close to permit limits, it is time to desludge
3) Recirculate water high in Dissolved Oxygen from Cell # 3 to Cell # 1 for odor control and improved water quality.
4) Quarterly perform intra-pond diagnostic BOD, CBOD, Ammonia, and Nitrate sampling between each treatment cell to understand the nature of the system and stay ahead of any potential problems.

Section 7 – Conclusions

CONCLUSIONS

The Mahnomen wastewater lagoon system is run by a competent operator doing a fine job in keeping the pond system within permit limitations. The Mahnomen pond system is healthy and is generally working well.

There is a ***where,* a *when,* and a *why*** to lagoon problem solving and optimization. Determining where treatment is not occurring is essential to optimizing Mahnomen, Minnesota's wastewater lagoon system, for continued sustainable permit compliance.

Please see Diagnostic BODs in the attachments and commit to routinely performing these kinds of tests.

Section 7 – Conclusions-Continued

Thank you for the opportunity to serve the good people of Mahnomen, Montana.

Steve Harris President

H&S Environmental, LLC

Attachments

1) Diagnostic BODs
2) Algae's Contribution to the BOD_5 Test Result
3) The Importance of Mixing Lagoon Sludge Blankets

References

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- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization
- Training

H&S Environmental, LLC.

2122 East Leland Circle   Mesa, AZ 85213   1 (480) 314-8410

Date: October 25, 2021

Ted Priester
Executive Director
Red River Basin Commission
1120 28th Avenue N, Suite B
Fargo, North Dakota 58201

Re: Performance Evaluation of the Thief River Falls Minnesota Wastewater Lagoon System

Ted,

Enclosed is the October 25, 2021 report for H&S Environmental's (H&S) performance evaluation of the Thief River Falls Minnesota Wastewater Lagoon System

The purpose of this report is to identify operational conditions and practices that should prevail to keep the effluent of the Thief River Falls Wastewater Lagoon System within permit limits.

All facility data, sludge depth data, and other field data used in this report were compiled by Thief River Falls and H&S Environmental, LLC (H&S).

The conclusions reached in this performance evaluation are based on five (5) primary data sources:

1) The results of intra-pond biological oxygen demand (BOD_5) testing by RMB Environmental Laboratories, Inc.
2) The analysis of four-point-eight (4.8) years of DMR data from the US EPA ECHO database
3) Field-testing of Ammonia, Nitrate, Alkalinity, Dissolved Oxygen, and pH results by the Thief River Falls and H&S Environmental, LLC
4) Sludge judging results by Thief River Falls and H&S Environmental, LLC
5) DEQ Permit # MN 0021431, September 1, 2021, to August 31, 2026

Performance Evaluation of the Thief River Falls Minnesota Wastewater Lagoon System

The City of Thief River Falls, Minnesota wastewater facility is located at
48 06 28.35N, 96 13 11.11W

Permit Number MN 0021431

October 25, 2021, 2021

Prepared for

The International Red River Board

Project Title:
Supporting the IRRB's Nutrient Management Strategy Through Workshops and Technical Assistance in the Red River Basin

Prepared by
H&S Environmental, LLC
Steve Harris, President

This document was prepared under contract with the IRRB

Disclaimer

This document assumes basic wastewater operations knowledge, skills, understanding, and compliance with applicable federal and state permit limits.

Acknowledgments

This performance evaluation was prepared with assistance from Ted Priester, Executive Director, Red River Basin Commission

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Figure 1. The Thief River Falls Minnesota, Facultative Wastewater Lagoon System

Executive Summary:

This report will focus on the results of field nutrient testing by H&S Environmental, sludge judging by H&S and Thief River Falls, laboratory analysis by RMB Laboratories, Inc, as well as 4.83 years of DMR data from the US EPA ECHO database for recommendations on optimizing the Thief River Falls wastewater lagoon system.

Field and laboratory samples were taken directly from the transfer structures of each treatment cell. The data from these samples show that final effluent BOD_5 and TSS are compliant and within permit limits. Effluent Ammonia was 0.10 mg/l, Soluble BOD was three (3) mg/l, and Ortho Phosphorous was 1.31 mg/l. Dissolved oxygen before sunrise in Cell # 1 was less than 0.61 mg/l on the day of field testing. In Cell # 1, dissolved oxygen levels recovered to over four (4) mg/l during the afternoon. Effluent pH was non-compliant on the day of field testing.

The primary ammonia removal pathway appears to result from nitrification, but volatilization through high pH and assimilation by algae also remove ammonia. There is a three-hundred and thirty-two (332) day retention time at Thief River Falls, giving the water time to exhaust nutrients producing clean water.

If Thief River Falls were required to discharge on the day of field testing and sampling, it would meet permit limits for BOD_5 and TSS but not pH.

Field testing of Dissolved Oxygen (DO) showed sufficient DO concentrations in Cells 2 & 3 for BOD_5, TSS, and Ammonia removal, but the Primary Treatment Cell was anoxic during the morning. If problems with odors occur or more ammonia removal is desired from Cell # 1, water high in DO can be recirculated back to Cell # 1 from Cell # 2, which has a DO of ten (10) mg/l during the afternoon.

Ammonia showed progressive reduction through all three (3) cells of the treatment system. Ortho-phosphorous also showed reduction through the pond system.

No treatment cells require sludge removal at this time. Cell # 1 should be desludged in five (5) years to estimate sludge accumulation rate and to determine when sludge will reach eighteen (18) inches in thickness. Because of the volume and considerable expense, it is best to set aside money for this expensive operation. Sludge should be removed when it reaches eighteen (18) inches in thickness or when effluent water quality approaches permit limits. Sludge has accumulated in Cell # 1 to an average of 0.92 feet and Cell # 2 to 0.51 feet. Cell # 3 was not sludge profiled because of the high winds and whitecaps.

Analysis of four-point-eight-years (4.8) years of DMR data show increasing trends in effluent TSS in mass and concentration (lbs. and mg/l), BOD_5 mass and concentration, effluent ammonia, and pH max. Data over the same period show a decrease in influent TSS, TSS Percent Removal, BOD_5 Percent Removal, and Flow.

For a wastewater lagoon system where everything affects everything else, Raw Sewage BOD is highly correlated to Total Phosphorous levels (mg/l) in samples taken on a quarterly basis. Correlation analysis show a close relationship between effluent BOD_5 and TSS.

Thank you.

Sincerely,

Steve Harris
President
H&S Environmental, LLC

Figure 2. Cells 1 & 2 of the Thief River Falls Wastewater Lagoon System

PERFORMANCE EVALUATION REPORT

Facility Name:	The City of Thief River Falls Minnesota Wastewater Lagoon System
Client:	The City of Thief River Falls, Minnesota, and The International Red River Board (IRRB)
Date of Field Sampling:	September 23, 2021
Data Review:	Dissolved Oxygen, pH, Ammonia and Sludge Field Sampling Results Intra-Pond BOD and Ammonia, RMB Labs, July 2021 Field Dissolved oxygen, pH, Temperature, Ammonia, Nitrate, Nitrite, and Alkalinity, and sludge blanket thickness by Thief River Falls and H&S Environmental, LLC, September 23, 2021 US EPA ECHO DMR date from October 2016 to August 2021 Permit: Final NPDES/SDS Permit, Permit No. MN0021431

Thief River Falls, Minnesota:

Wayne Johnson, Public Works Director
Nick Trudeau, Operations Supervisor
Ben Myers, Operator
Trentyn Graslie, Operator

The International Red River Board:

Mr. Ted Priester, Executive Director

H&S Environmental, LLC: Steve Harris, President, Mesa, AZ

Report Prepared By:
Steve Harris,
President, H&S Environmental, LLC
October 25, 2021

Section 1

Introduction and Background

1.0 Scope and Purpose

In September 2021, H&S Environmental and Ted Priester met at the Thief River Falls wastewater lagoon system to test the system's water quality and take samples for RMB Lab testing. After a thorough review of Thief River Falls' field, lab, and DMR data, Steve Harris of H&S Environmental, LLC (H&S) prepared this performance evaluation.

The information used in this performance and optimization evaluation includes the following:

- Phone interviews, email contact, and in-person interviews with Wayne Johnson, Public Works Director of Thief River Falls, Minnesota, on the history and general condition of the lagoon system
- Analysis of 2016 through 2021 DMR data.
- The results of intra-pond nutrient sampling, dissolved oxygen sampling, sludge judging by H&S, Thief River Falls, and Intra-pond BOD_5 testing by RMB Labs.

The purpose of this evaluation is to identify ways to improve the treatment process to meet permit limits in a long-term sustained manner.

This report will focus on methods to keep the Thief River Falls system within permit limits. To determine if in-pond optimization is possible, H&S Environmental will analyze and evaluate lagoon system performance with respect to (i) historical data reviewed, (ii) additional data gathered from field testing and sampling, and (iii) a review of sampling and testing protocols practiced by Thief River Falls Minnesota utility personnel.

This report covers the Thief River Falls Lagoon System performance as it existed up to September 2021.

Findings

Section 2 – Findings

2.0 Findings

The results of intra-pond sampling performed by H&S and Thief River Falls (September 23, 2021) are presented below.

Section 2 – Findings

1. Laboratory analysis by RMB Labs shows Effluent BOD_5 is within permit limits

2. Laboratory analysis by RMB Labs shows Effluent TSS is within permit limits

3. Effluent Ammonia tested 0.59 mg/l by H&S Environmental, LLC

4. Effluent Ortho-Phosphorous measured 1.31 mg/l by H&S Environmental, LLC

5. Three (3) mg/l of Effluent BOD_5 is caused by algae respiring in the BOD_5 test bottle. SBOD = 3

6. Dissolved Oxygen measured in the morning, before the production of oxygen through photosynthesis, measured between 0.27 and 2.05 mg/l in Cell # 1. In Cell # 2, Dissolved Oxygen measured between 5.62 and 7.95 mg/l. In Cell # 3, predawn DO measured 5.94 to 10.87 mg/l.

7. Long retentions times, algae assimilation, and high pH, along with nitrification, are the major ammonia removal pathways. Nitrification does not appear to play a significant role in ammonia removal at Thief River Falls due to the lack of nitrate production and low $NBOD_5$ (BOD_5 – $CBOD_5$). $NBOD_5$ is considered the relative number of nitrifying bacteria in a system.

8. pH as measured morning and afternoon was outside permit limits and during the afternoon measured 9.19 at its highest point at the Cell # 3 discharge point.

9. Sludge averaged 0.92 feet in Cell # 1 and 0.51 feet in Cell # 2. Sludge volume in Cell # 1 is estimated to be 39,184,076 gallons. In Cell # 2, there are an estimated 21,314,111 gallons of sludge. Due to high winds and whitecaps, Cell # 3 was not sludge judged.

10. Retention time, assuming accumulated sludge and NO short-circuiting is three-hundred and thirty-two (332) days. Calculated retention time is based on a flow of 1.28 gallons/day (from DMR Data submitted by Thief River Falls) and measured water depths.

11. The Trend in Influent Monthly Average Flow is Decreasing

12. The Trend in Effluent pH is Increasing

13. There is a four (4) year Upward Trend in both Monthly Average BOD_5 and TSS and a corresponding downward Trend in BOD and TSS Removal Efficiency

14. There is a four (4) year downward trend in Sodium, Chloride, Sulfate, Bicarbonate, Phosphorous, and Nitrate

15. Loading to the Thief River Falls appears to be normal for a shallow facultative system in MN 21.3 lbs./acre based on 1.28 ADF and average CBOD of 268 mg/l (4.8 years of DMR Averages).

Section 3 – Recommendations - Continued

RECOMMENDATIONS

Based on the analysis of Intra-pond Field Sampling results and the analysis of DMR data, below are recommendations for improved stabilization pond performance for long-term sustained compliance using the existing wastewater stabilization pond system.

The object of the recommended changes to the Thief River Falls wastewater lagoon system is intended to keep Thief River Falls permit compliant in a long-term sustainable manner.

Five (5) recommendations for the Thief River Falls Minnesota wastewater lagoon system are:

1) Tighten up the collection system for greater influent BOD and TSS numbers or Sample the Influent More Frequently
2) Prepare now for the expense of desludging Cell # 1
3) Keep a close eye on the upward trends in BOD, TSS, and ammonia and desludge when these numbers approach permit limits
4) If odors occur or more ammonia removal is desired from Cell # 1, water high in DO can be recirculated back to Cell # 1 from Cell # 3, which has a DO of over ten (10) mg/l during the afternoon.
5) Quarterly perform intra-pond diagnostic BOD, TSS, Ammonia, and Nitrate to monitor the success of any changes. Remember, the lagoon system is subject to seasonal changes in the water temperature and length of the day. Therefore look to yearly changes in pond behavior for the success of any changes.

1) <u>Tighten Up the Collection System</u>

Quarterly sampling and dilute influent TSS cause poor TSS removal efficiency and permit violations. The Thief River Falls system has violated its permit limits three (3) days over five (5) years; 5/31/2016, 5/31/2020, and 6/31/2021. Fifty (50) percent of the time violations are for TSS percent removal. A dilute influent TSS of 122 mg/l weakens Thief River Falls's ability to remove TSS to permit standards, and an influent TSS of fifty (50) mg/l (9/2018 and 10/2019) is not uncommon. Some of the best upgrades for lagoons are made in the collection system. Thief River Falls could also sample the influent more frequently to raise influent numbers.

2) <u>Begin Now to Plan for Desludge Cell # 1</u>

Sludge has accumulated to 0.92 feet in Cell # 1. Typically sludge is removed when it reaches 1.5 feet to avoid benthal feedback…the feeding of algae cells with nutrients released from the sludge blanket.

Laboratory results show excellent Cell # 1 BOD removal (95%) from the influent to the effluent of Cell # 1. There was a 99.3% overall BOD_5 removal from the system. The Thief River Falls lagoon system is BOD and TSS compliant, and ammonia leading to elevated effluent BOD_5 also shows good removal efficiency through the system.

At current water levels, sludge in Cell # 1 occupies twenty-five-point six (25.6) percent of the capacity. In Cell # 2, sludge occupies about thirteen-point-four (13.4) percent of the treatment cell's capacity. Sludge can cause elevated BOD if there is nutrient feedback from the sludge blanket.

Effluent TSS is compliant at 10.4 mg/l. The release of nutrients from a sludge blanket can feed algae growth causing high effluent TSS and CBOD. There are upward trends in effluent ammonia, TSS, and CBOD with a corresponding decrease in influent Flow and influent BOD_5 and TSS. TSS removal efficiency on the day of field testing was ninety-seven-point-four (97.4) percent.

Section 3 – Recommendations - Continued

3) Keep an Eye on Increasing Trends in Effluent TSS, BOD, and Ammonia

Increasing trends in effluent BOD, TSS, and ammonia are signs of benthal feedback; the release of nutrients causing algae growth leading to TSS, $CBOD_5$ violations, and problems with diminishing percent removal efficiency. Watch these numbers closely.

4) Recirculate Water High in Dissolved Oxygen from Cell 2 or 3 Back to Cell # 1

If greater ammonia removal is desired in Cell # 1 or odors or popping sludge becomes a problem, water high in dissolved oxygen can be recirculated from Cell # 3 to Cell # 1 during the afternoon when Cell # 3 DO is the highest. Loading comes from two (2) sources, 1) the sludge and 2) the daily influent BOD_5 loading.

In Cell # 1, at 8:31 in the morning, dissolved oxygen concentrations were between 0.27 and 2.05 mg/l. In Cell # 3, DO levels were higher, measuring between 10.64 and 13.39 during the afternoon. This high DO is a resource and can be recirculated back to Cell # 1 to control odors and improve ammonia removal. A simple two (2) inch trash pump is all that is needed. In the afternoon, after 12:31 PM, high DO water can be recirculated back to Cell # 1 using a trash pump to stop odors and provide the oxygen necessary for improvement in water quality.

Figure 3. Cell # 3 of the Thief River Falls Wastewater Lagoon System.

4. Quarterly Perform Intra-pond Diagnostic BOD, TSS, Ammonia, and Nitrate to Monitor the Success of Any Changes.

Intra-pond testing is how to evaluate changes made to a lagoon system. Start by measuring effluent BOD, Ammonia, Nitrate, and DO at the effluent of all cells. When changes to the treatment system are made, judge performance based on improvements in intra-pond BOD_5, $CBOD_5$, Ammonia, Nitrate, and Dissolved Oxygen test results.

Operational Notes:

To evaluate and understand the effects of the changes that are made to the Thief River Falls Minnesota wastewater lagoon system, BOD_5, $CBOD_5$, Temperature, Ammonia and Nitrate concentrations, DO, and pH must be routinely be made and recorded. These tests will enable the operators to make sound decisions when making changes to the system and monitor those changes for success.

Intra-pond testing will help operations staff focus on specific areas where problems (opportunities for optimization) occur. Pinpointing where, when, and why a problem occurs saves time and money and simplifies lagoon optimization for Ammonia and $CBOD_5$ removal.

More than any other process control test, Cell # 1 effluent BOD_5 removal efficiency and ammonia removal efficiency through each cell of the system will tell operations personnel when the influent loading is becoming a problem or if changes have taken effect. Determining removal efficiency requires pulling a BOD_5 sample from the Effluent of Cell # 1 while an influent BOD_5 sample is drawn and tested. Compare the two results. Cell # 1 removal efficiency should be at least eighty (80) percent. Operations staff should strive to keep Cell # 1 effluent BOD to less than 31 mg/l to ensure good ammonia removal from the other treatment Cells in the system.

BOD_5 should also be measured from the effluents of Cells # 1 & 2. $BOD_5 – CBOD_5 = NBOD_5$. $NBOD_5$ is the relative number of nitrifying bacteria in a system and denotes nitrification is or has the potential of occurring.

As much as possible, treatment should be "pushed back" to Cell # 1. Pushing BOD removal back to Cell # 1 is accomplished by adding sufficient DO to ensure DO is above two (2) mg/l at all times of the day and night, desludging, and stopping short-circuiting. Higher treatment levels in Cell # 1 will allow for better Ammonia and Nitrate removal in subsequent cells. Cell 2 should be for the conversion of Ammonia to Nitrate to Nitrogen gas and settling dead bacteria and algae cells clarifying the water. This objective is more easily accomplished by getting the most productivity out of Cell # 1 as possible.

The Thief River Falls lagoon system is producing good numbers at the time of field testing and sampling and is compliant with its permit limits except for pH.

Monitor water quality trends over time.

Figure 4. Cell # 2 of the Thief River Falls Wastewater System.

Figure 5. Cell 1 & 2 of The Thief River Falls Wastewat Lagoon System

Field Testing Data Analysis

Dissolved Oxygen Concentrations

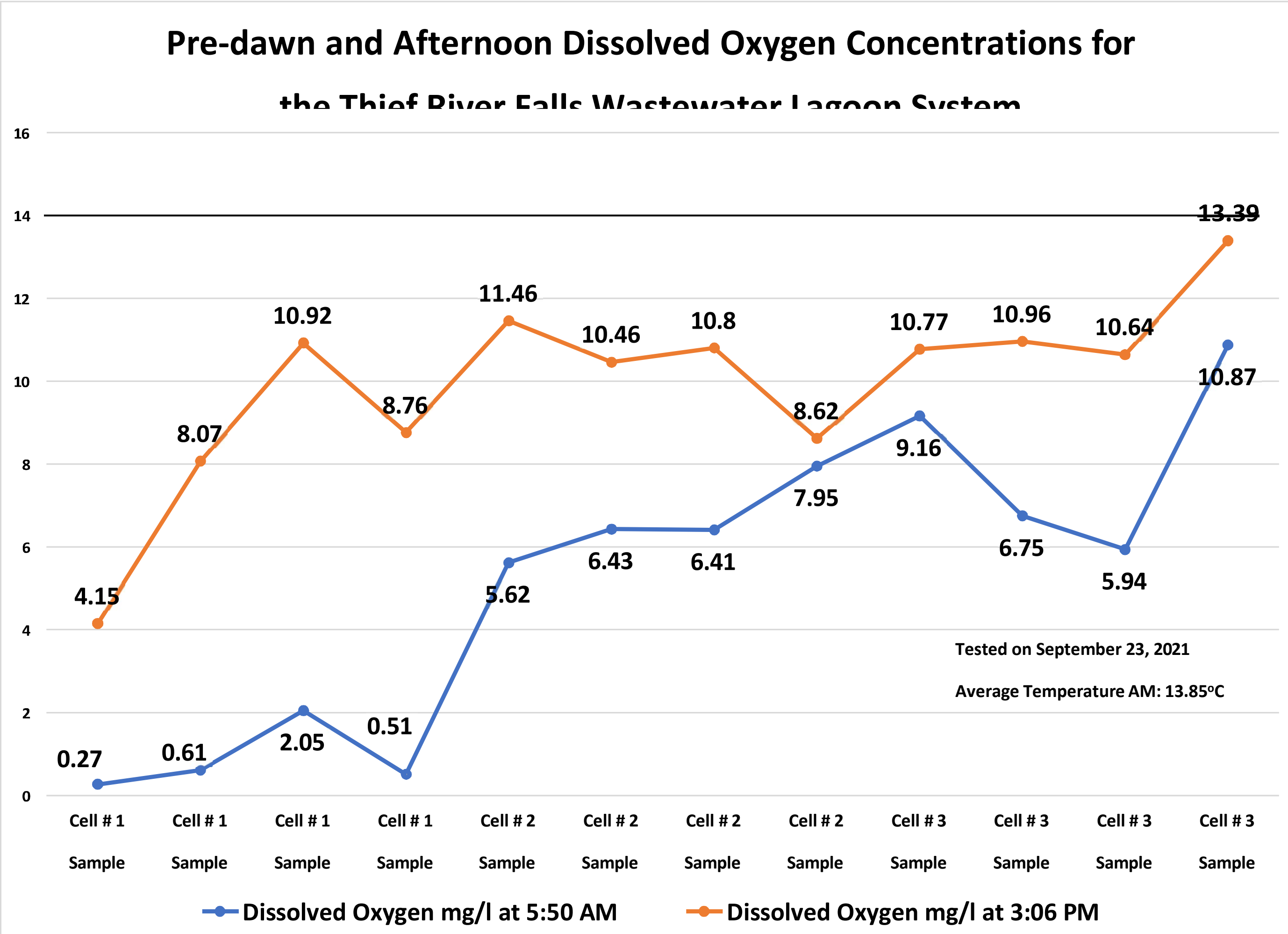


Figure 6. Predawn and Afternoon Dissolved Oxygen Concentrations.

Always keep dissolved oxygen concentrations above two (2) mg/l for greater $CBOD_5$, ammonia removal, odor control, and optimal performance.

There are two loading sources for the Thief River Falls wastewater lagoon system, 1) the loading coming in daily, and 2) the sludge blanket. Nutrients are stored in the bodies of dead bacteria, algae, and protozoa that make up the sludge blanket. This sludge feeds nutrients and soluble BOD back into the water column, putting a strain on the system. This loading manifests itself in low dissolved oxygen concentrations and increasing effluent TSS, CBOD, and ammonia trends.

Low DO in Cell # 1 can be supplemented using a simple two (2) inch trash pump and recirculating water high in DO from Cell 2 or 3 to the influent of Cell # 1.

Section 4 – Field Data Analysis

<u>Dissolved Oxygen Profile Taken by Boat from the Middle of Cell # 1</u>

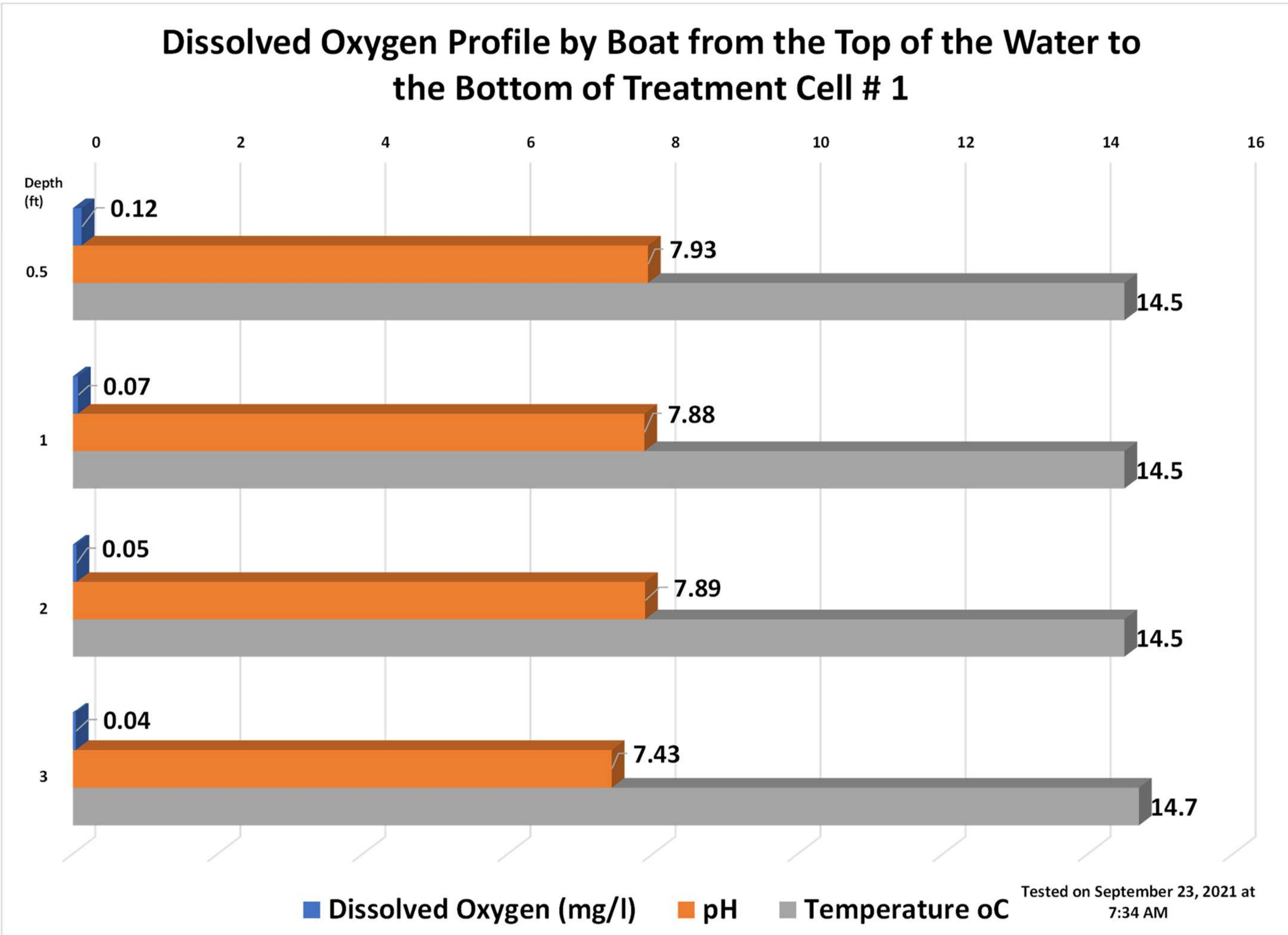


Figure 7. Cell # 1 Dissolved Oxygen Profile

Recirculation of water from Cell # 2 or 3 to Cell # 1 can lift the DO levels in this cell to prevent odors and provide better treatment.   Let your DO and pH meter dictate when the trash pump will run. Typically, a recirculation trash pump is run from 1:00 PM to 7 PM.

Measure DO in the second treatment cell to ensure recirculated water is over five (5) mg/l of Dissolved Oxygen. Recirculated water should be drawn from the very upper surface of the cell. Floats are added to the suction line of the trash pump.

Section 4 – Field Data Analysis

RMB Laboratories Intra- Pond BOD_5 Test Results

On Monday, September 23, 2021, samples were delivered to RMB Labs for intra-pond BOD_5 analysis. Below are the results.

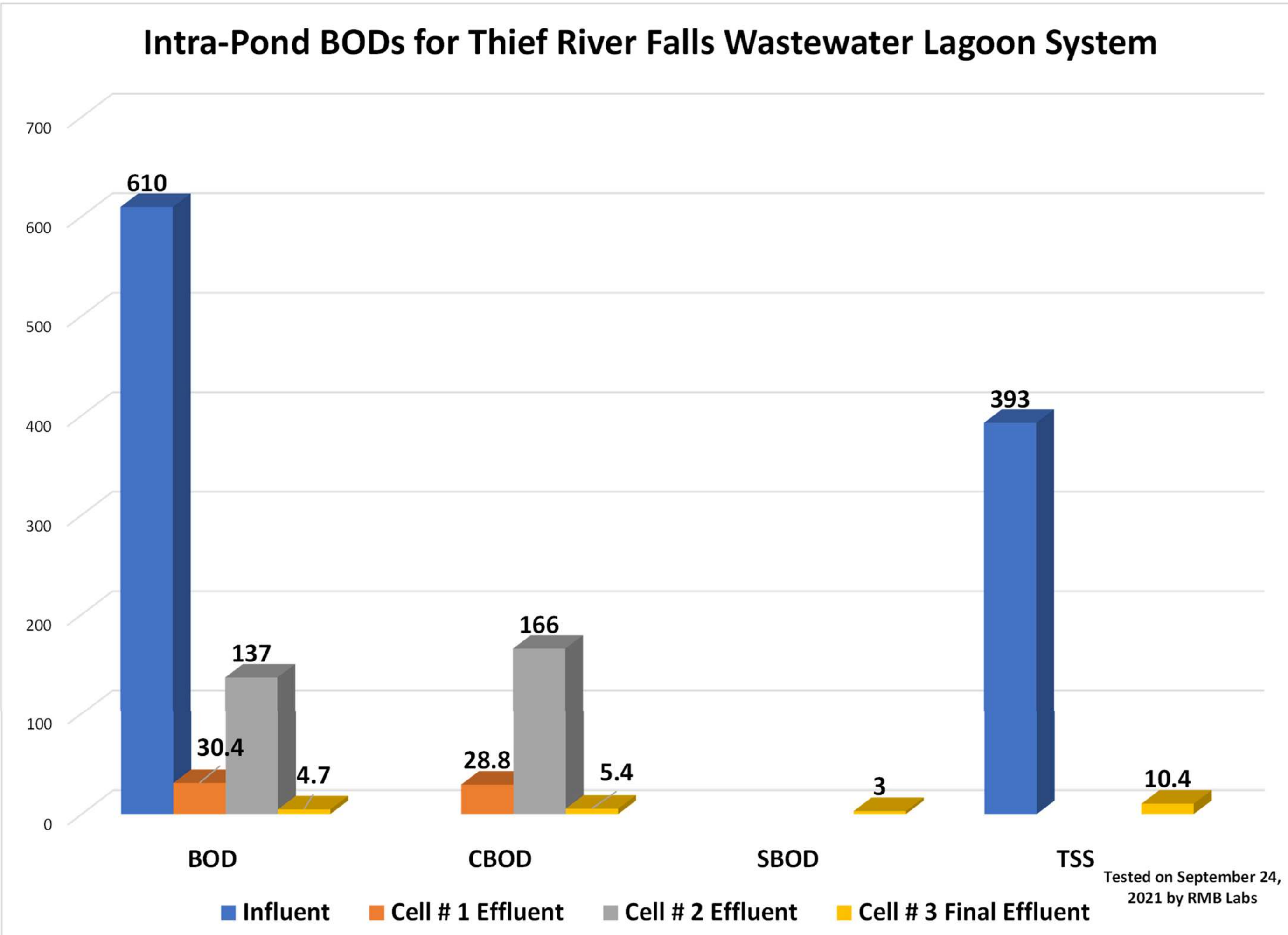


Figure 8. Intra-pond BOD_5, TSS, and Ammonia Results from RMB Labs

Benthal feedback is where the sludge feeds BOD_5, TSS, and algae growth by releasing nutrients once tied up in the cells of dead algae and bacteria that make up the sludge blanket.

Algae is the number one cause of BOD_5 violations in the US because algae consume oxygen for five (5) days under dark conditions in the BOD_5 test bottle and incubator. When the lights are off algae, switch to oxygen consumption. That is why the most meaningful Dissolved Oxygen test is performed during the morning before sunlight hits the pond system. The BOD without Algae (SBOD) is three (3) mg/l in Thief River Falls. The ten-point-four (10.4) mg/l of TSS does not require much oxygen and does not significantly interfere with the effluent BOD numbers.

Section 4 – Field Data Analysis

Field Nutrient Testing

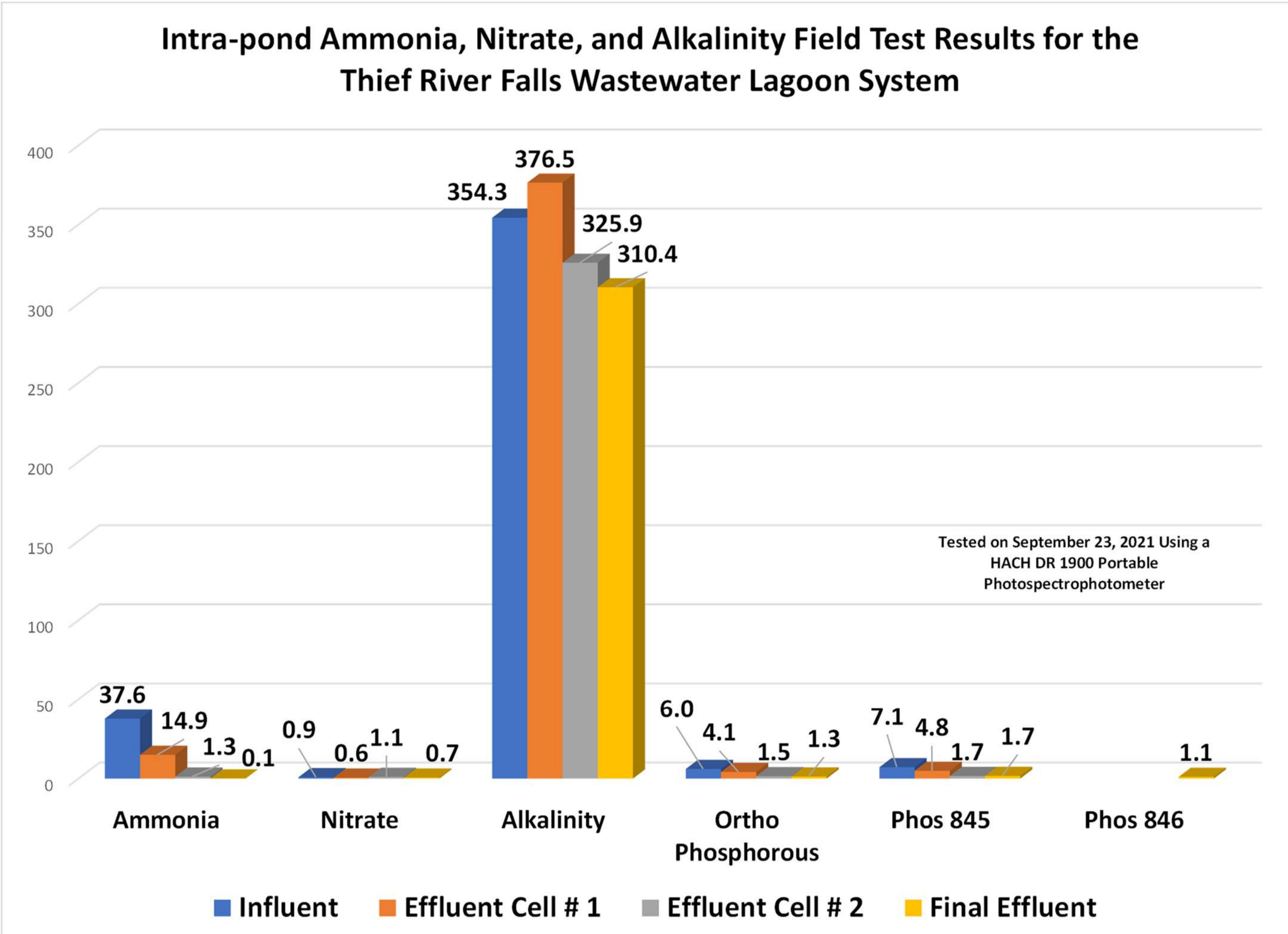


Figure 9. Intra-Pond Ammonia, Nitrate, Alkalinity, and Ortho-Phosphorous Results from Field Measurements

Ammonia removal is excellent. The primary ammonia removal pathway appears to be volatilization by high pH, algae assimilation, and then nitrification in Cells 1 & 2.

Section 4 – Field Data Analysis

Sludge Accumulation

Thief River Falls Sewer Lagoon					
Sludge Blanket Volume and Retention Time Summary					
Item	Units	**Cell # 1**	**Cell # 2**	**Cell # 3**	**Totals**
Bottom Length	feet	**2630**	**2920**	**1964**	
Bottom Width	feet	**2160**	**1910**	**1924**	
Side Slopes	1 to	**3**	**3**	**3**	
Average Sludge Depth	feet	**0.92**	**0.51**	**0.0001**	
As-Built Bottom Elevation	feet	**0.00**	**0.00**	**0.00**	
As-Built Top-of-Bank Elevation	feet	**7.00**	**7.00**	**8.00**	
Bottom Area	sq ft	5,680,800	5,577,200	3,778,736	
Top of Sludge Length	feet	2635.52	2923.06	1964.0006	
Top of Sludge Width	feet	2165.52	1913.06	1924.0006	
Top of Sludge Area	sq ft	5,707,271	5,591,989	3,778,738	
Sludge Volume	cu ft	5,238,513	2,848,143	378	8,086,656
Sludge Volume	**gallons**	**39,184,076**	**21,304,111**	**2,826**	**60,488,187**
Embankment Height	feet	7.00	7.00	8.00	
Freeboard Required	feet	**2**	**2**	**2**	
Useable Lagoon Depth / Remaining Water Cap after Sludge	**feet**	**2.66**	**3.31**	**6.00**	
Top of Water Max Length	feet	2650	2940	2000	
Top of Water Max Width	feet	2180	1930	1960	
Top of Water Max Area	sq ft	5,777,000	5,674,200	3,920,000	
Lagoon Volume	cu ft	15,238,874	18,621,067	23,096,208	33,859,941
Usable Lagoon Volume at Current Operating Depths with Sludge	**gallons**	**113,986,778**	**139,285,581**	**172,759,636**	**426,031,995**
AVE Daily Flow: 1.28 MGD (DMR)					
Retention Time Based on Sludge Volume and Actual Operating Depths, with Remaining Water Cap Capacity	days	**89.05**	**108.82**	**134.97**	**332.84**
Notes & Cautions:					
Cell # 3 was not sludge judged due to very high winds and whitecaps					
Elevations are estimates and the bottom of Cell # 1 varied by 9.96 inches and Cell # 2 by 14.0 inches					
Dimensions are estimates from Google Earth					
Rounded corners exist, square corners are used in the calculations above					
Averages of water depths and average sludge blanket thickness are used					
Slopes are assumed at 3:1					
Freeboard needed is assumed					
Flow is taken from DEQ Records.					

Figure 10. Sludge Blanket Volume and Retention Time Calculations.

Section 4 – Field Data Analysis

On September 17, 2021, a sonar sludge survey was conducted from the top of the water's surface down to the surface of the sludge.

The sludge survey procedure followed by H&S Environmental was performed differently. Using H&S's method, a survey level rod was used to measure the water depth at twenty (20) sample points in the lagoon. At the same time, an infrared sludge level detector set at medium was used to detect the top of the sludge blanket. Excel calculated the difference between the top of the water and the top of the sludge, effectively measuring sludge blanket thickness.

Because the bottom of Cell # 1 varied by an average of 9.96 inches, the difference between the two testing protocols produced a different result. Team Lab reports 41,450,354 gallons of sludge at 1.2 feet, and H&S Environmental reports 39,184,076 gallons of sludge and 0.92 feet.

Aside from occupying valuable capacity and lowering a treatment cell's retention time, sludge releases nutrients and soluble BOD back into the water column. These nutrients feed TSS production through algae growth. Because they consume oxygen under the dark conditions of the BOD_5 test, algae can result in high BOD_5. The release of nutrients from sludge feeds algae growth resulting in TSS permit violations.

Once sludge reaches about eighteen (18) inches in thickness, it is time to consider removal to prevent nutrient feedback causing problems with increases in algae growth leading to TSS problems.

Sludge removal options include dredging, pressing or centrifuging, and hauling off-site, as well as removing in situ with chemical oxidizing agents. Each method has its place. Sludge can also be pumped out and applied to a Geo-Tube or drying bed to dry on-site for two (2) years. Drying on-site allows for the removal of the water, reducing tipping fees and hauling costs. When dredging or drying, and scraping, the treatment cell must typically be taken offline.

Dredging mixes a treatment cell releasing Ammonia, Nitrates, phosphate, and CO2 to stimulate algae and bacteria growth. The filtrate from a belt press will concentrate nutrients as it squeezes sludge, creating a stream of nutrient-rich water that will load the plant. This nutrient-rich filtrate stream will, in most cases, cause a crash in DO and create odors. Be aware of the centrate or filtrate coming off the centrifuge, press, or weepage from a Geo-tube or runoff from a drying bed. Add air to the remaining working treatment cells when desludging. Keeping air above two (2) mg/l will keep odors and nutrient loading to a minimum.

If time permitted, mixing the sludge blanket and adding agricultural stubble breakdown chemistries can remove several feet of sludge over time. Mixing and chemical agents will not remove sand grit or gravel and leave dead bacteria bodies (Humus). The disadvantage of treating in place by mixing and adding is that you run the risk of freeing Ammonia, Nitrate, phosphate, CO_2, and organic acids to feed an algae bloom. Consult an expert before mixing a treatment cell. There are proven chemical additives from the agricultural industry that can accelerate sludge removal on-site associated with mixing.

Section 4 – Field Data Analysis

Aeration and Dissolved Oxygen

There are seven (7) indicators that the dissolved oxygen levels in Thief River Falls Minnesota pond system are too low:

1) Poor BOD_5 removal efficiency
2) Low ammonia removal efficiency
3) Odors
4) Popping sludge in the treatment Cells
5) *Daphnia* turned red in the treatment Cells
6) Low DO measurements both day **and** night. The best, most meaningful time to measure DO is before sunrise before algae have had the chance to produce dissolved oxygen
7) Increasing trends in effluent BOD_5 after all the Cells have been desludged

Dissolved oxygen measurements taken at the surface may not tell the whole story. While the surface water may appear to have sufficient DO, it may be anoxic just below the surface, beginning two to three feet below the surface. Measuring Dissolved Oxygen by boat in the middle of a treatment cell from the surface to the bottom at the sludge water interface is the best way to perform a DO profile. This type of DO profile is also best performed at or before sunrise.

Section 4 – Field Data Analysis-Continued

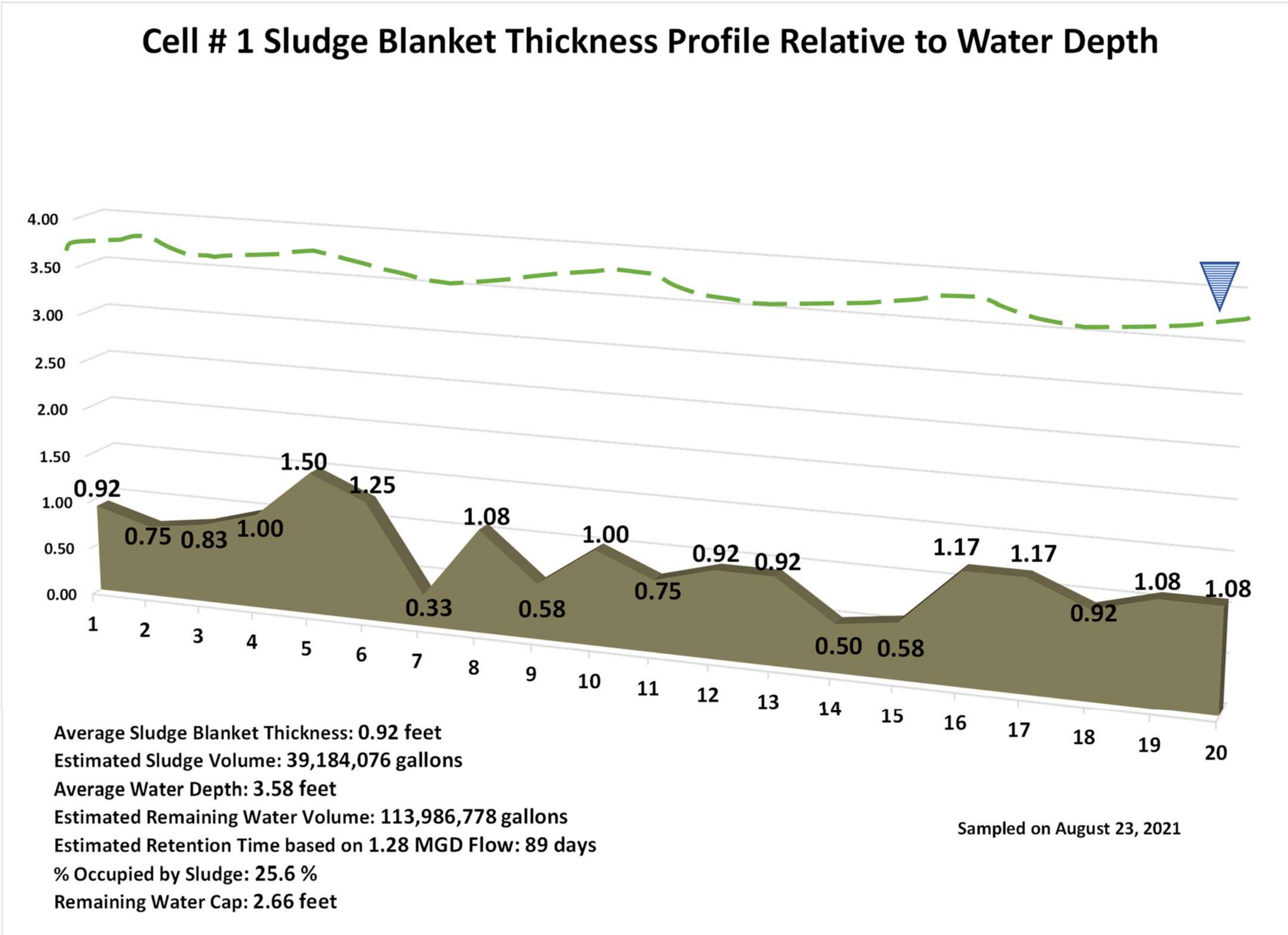


Figure 11. Cell # 1 Sludge Blanket Profile Relative to the Top of the Water

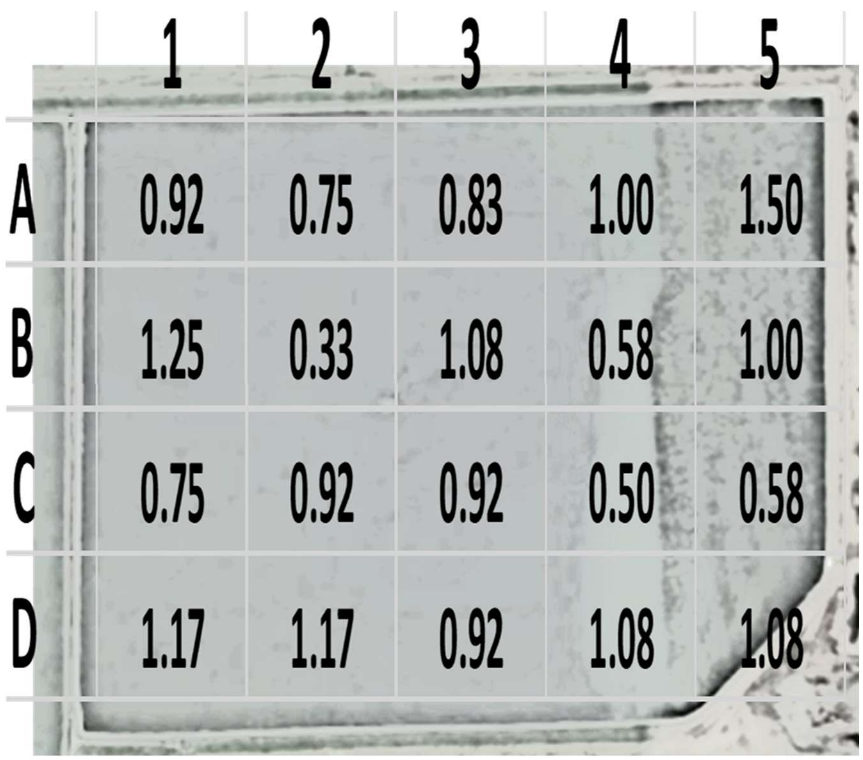


Figure 12. Cell # 1 Sludge Blanket Locations

Section 4 – Field Data Analysis Cont-

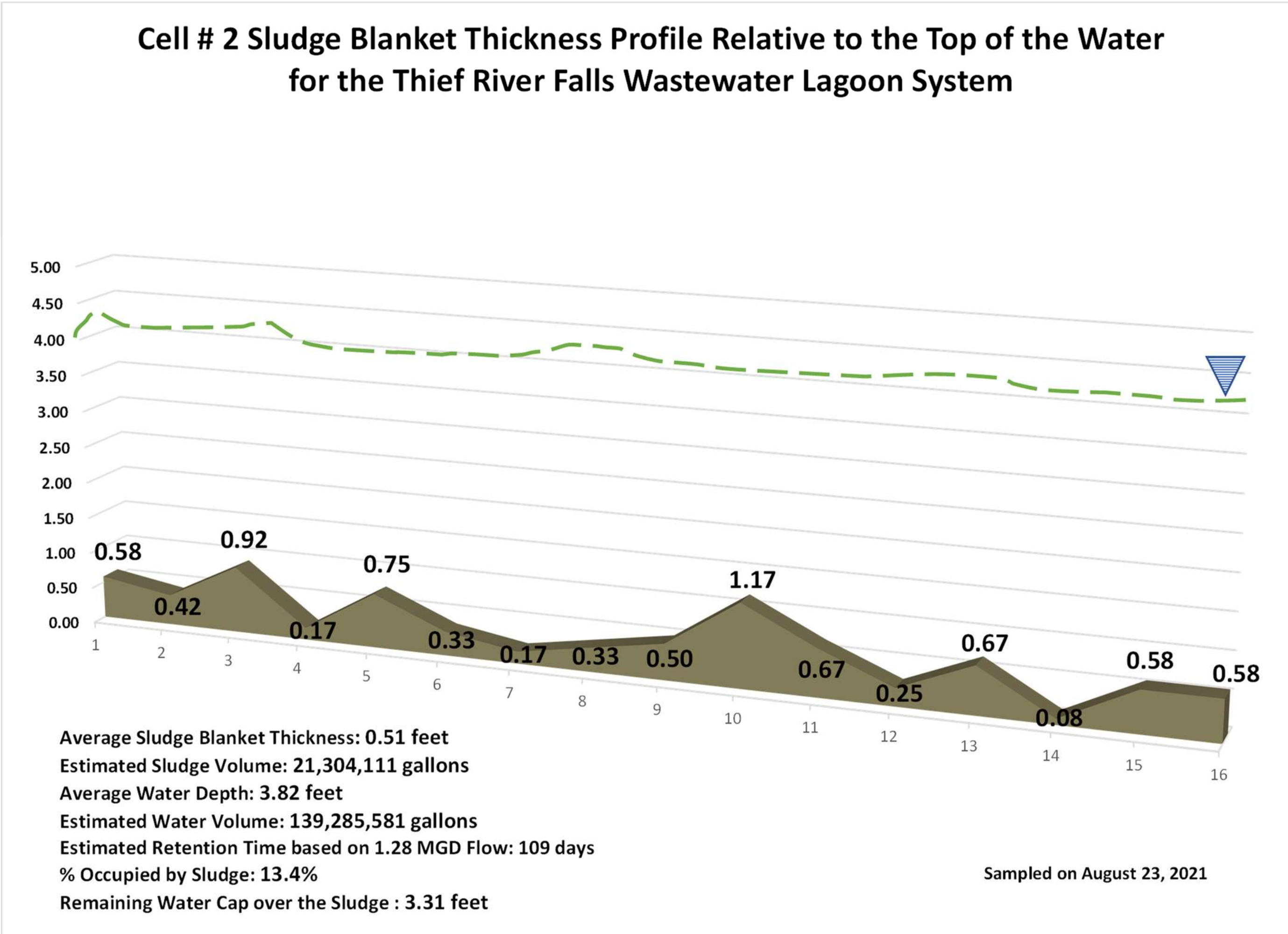


Figure 13. Cell # 2 Sludge Blanket Thickness Profile Relative to the Top of the Water

Sludge has a powerful impact on the effluent water quality of lagoon systems and should not be allowed to accumulate past eighteen (18) inches. Because it is so expensive to remove, the City of Thief River Falls should begin to save for the inevitability of desludging.

Lagoons fail for two (2) main reasons; 1) Poor hydraulic design (short-circuiting) and 2) Sludge accumulation.

Short-circuiting is the worst thing that can happen to a lagoon system short of someone dumping toxic waste in the system. Sludge is the second worst thing that can affect effluent quality. Sludge stores the nutrients once assimilated and then releases them back to the water column as the dead algae and bacteria cells lyse.

Algae growth cause CBOD problems by consuming oxygen, not making it, when the lights are off. For five (5) days, a sample sits in a BOD_5 test bottle under dark conditions, and algae consume oxygen over those five (5) days inflating the BOD_5 test result. Sludge feeds algae growth, and algae growth leads to TSS violations and BOD problems because of this.

In the New England States, there is a mandate to remove sludge after it reaches eighteen (18) inches in thickness because of the problems it creates.

Section 4 – Field Data Analysis Cont-

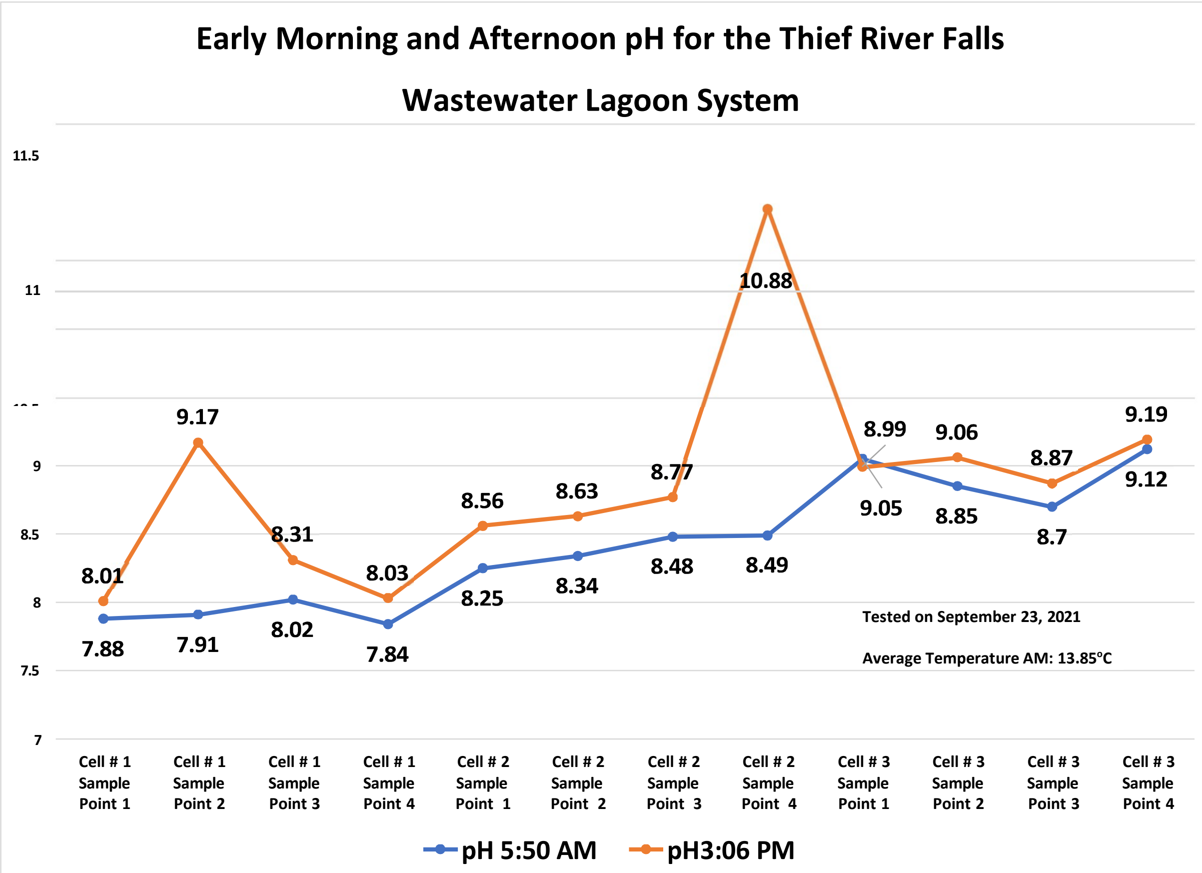


Figure 14. Morning and Afternoon pH

If required to discharge on September 23, 2021, Thief River Falls would meet permit parameters for everything but pH.

Section 5 – DMR Data Analysis

The trend in Average Monthly BOD in kg/day is slowly increasing. So also, is the Monthly concentration.

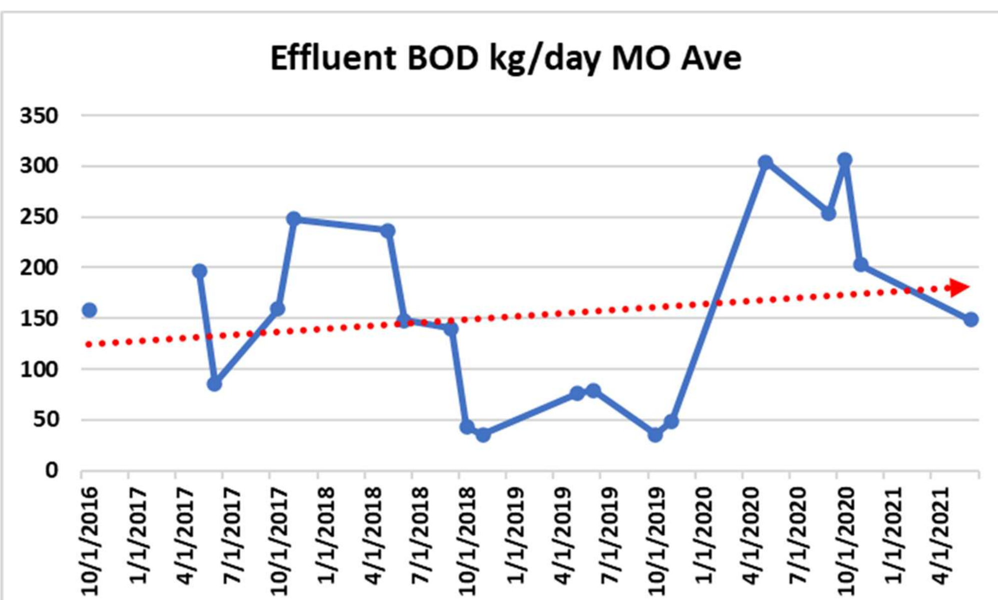


Figure 15. The Trend in Effluent BOD is Rising

Section 4 – DMR Data Analysis Cont-

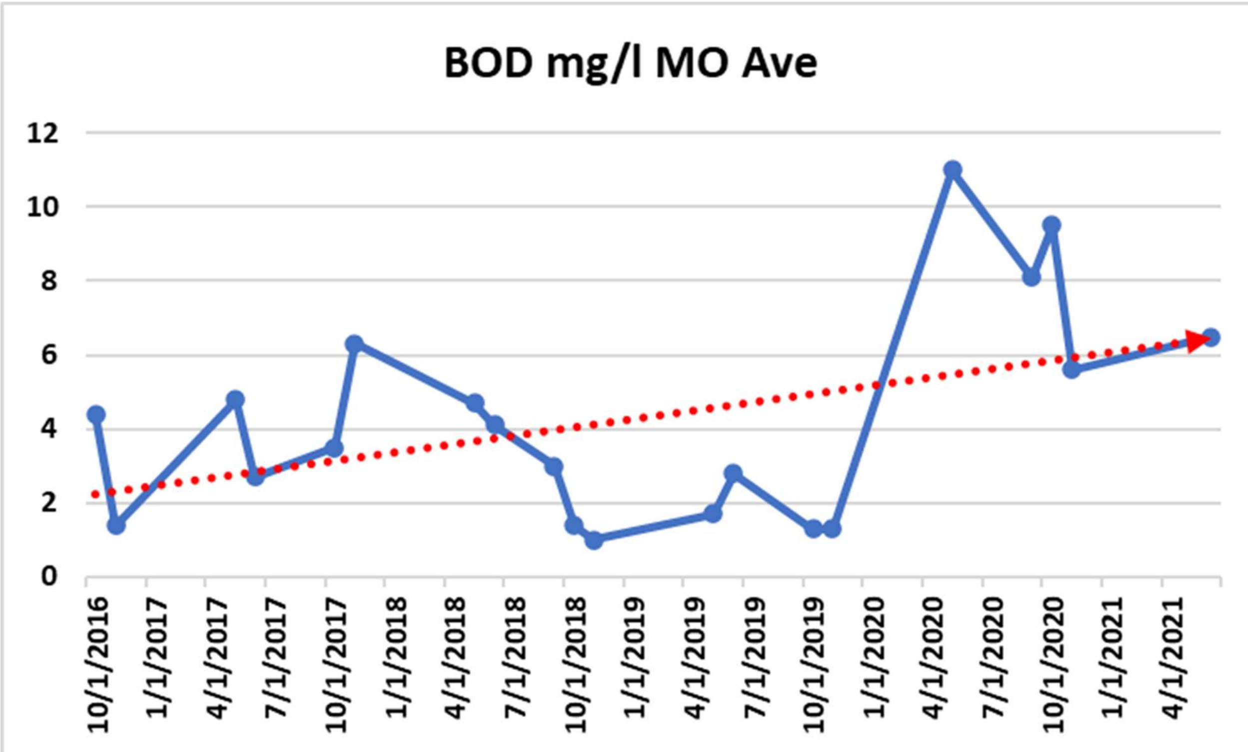


Figure 16. Monthly Average Effluent BOD Trending Up

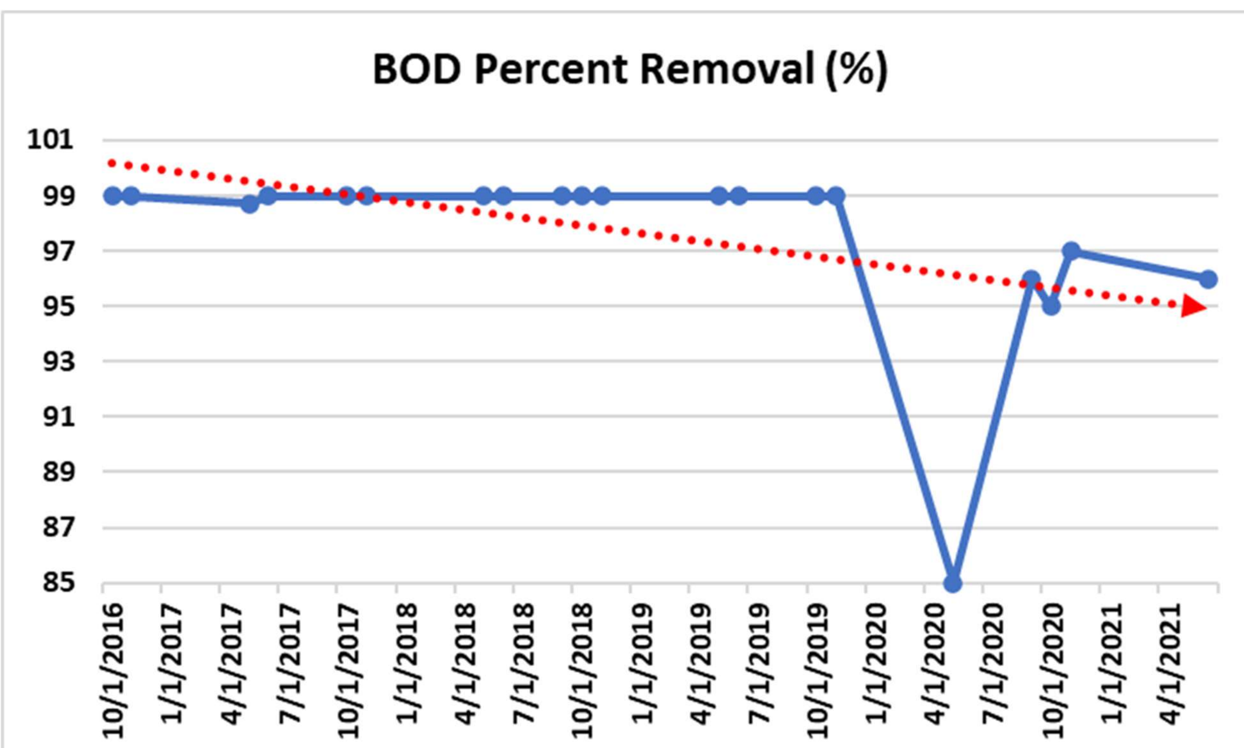


Figure 17. Monthly Average Effluent BOD Percent Removal is Trending Down

Section 4 – DMR Data Analysis Cont-

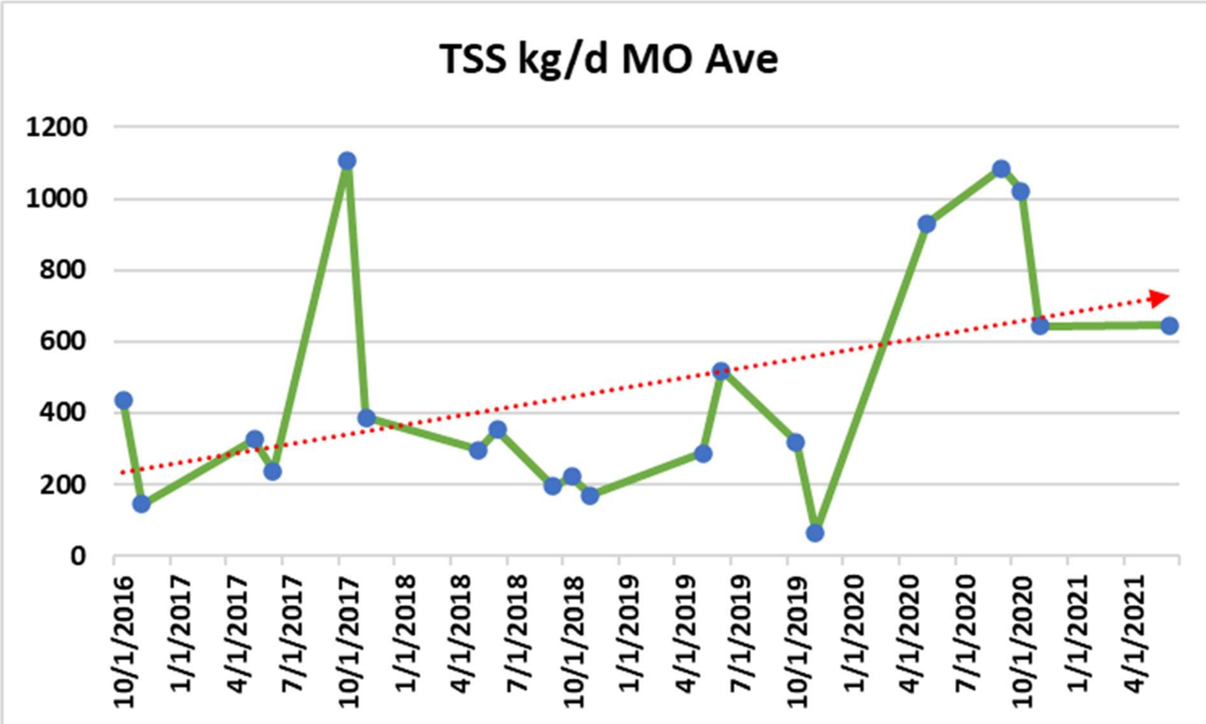


Figure 18. Effluent TSS kg/day MO Ave Trending Up

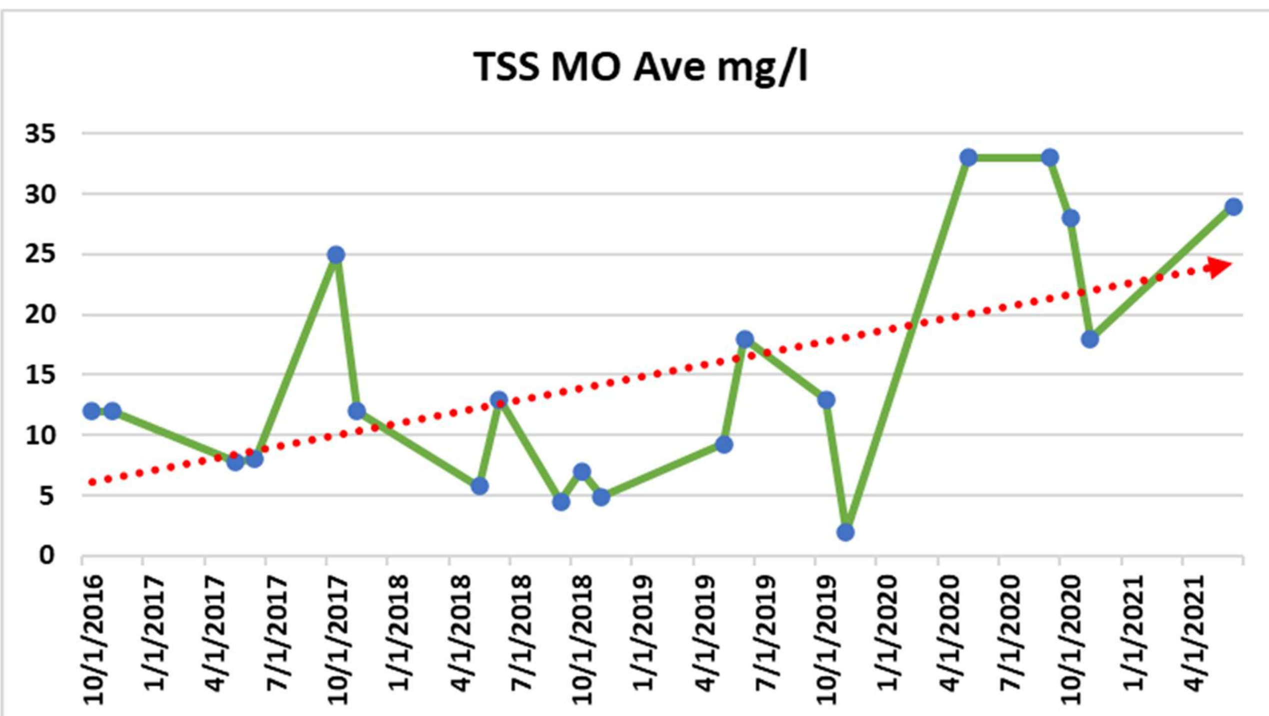


Figure 19. Effluent TSS mg/l Mo Ave Trending Up

Section 4 – DMR Data Analysis Cont-

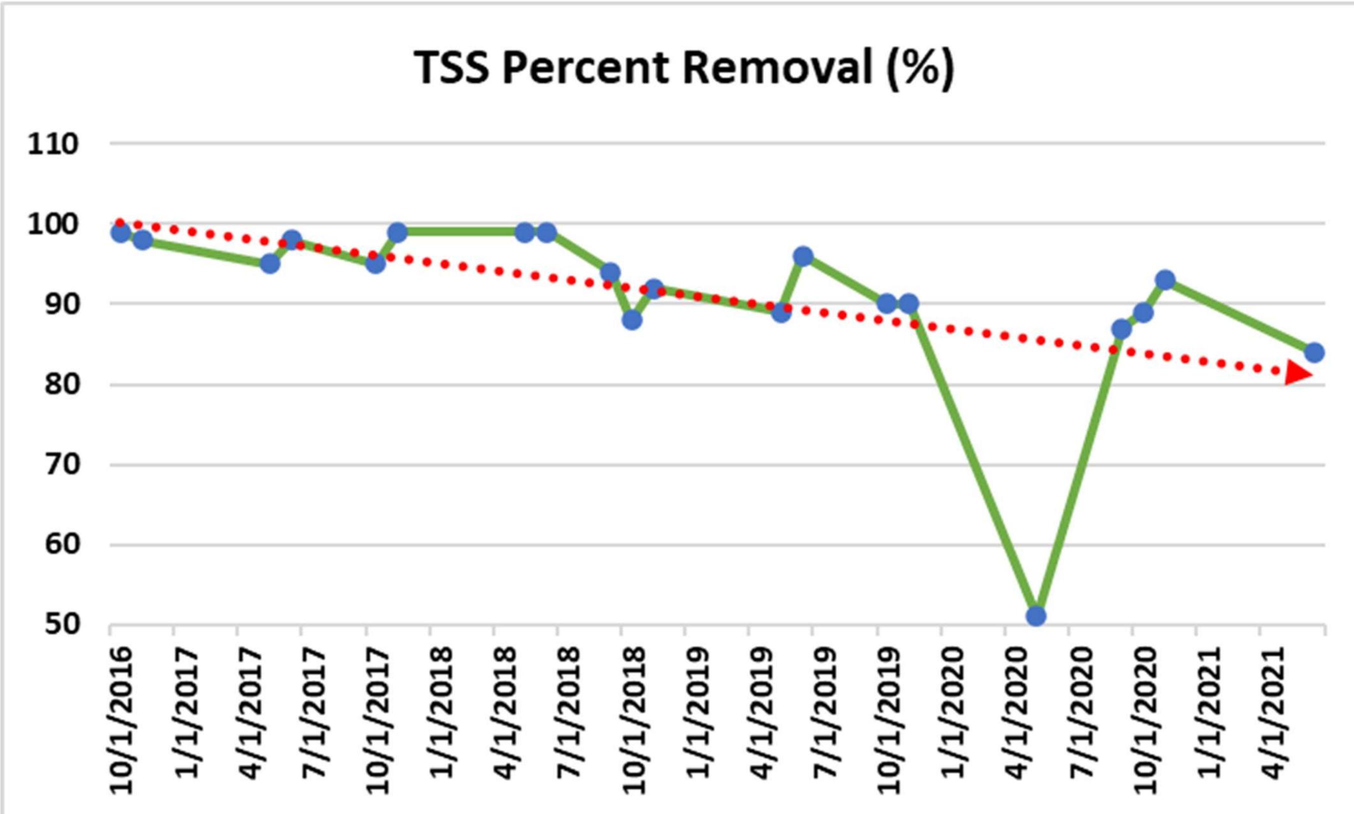


Figure 20. TSS Percent Removal Trending Down

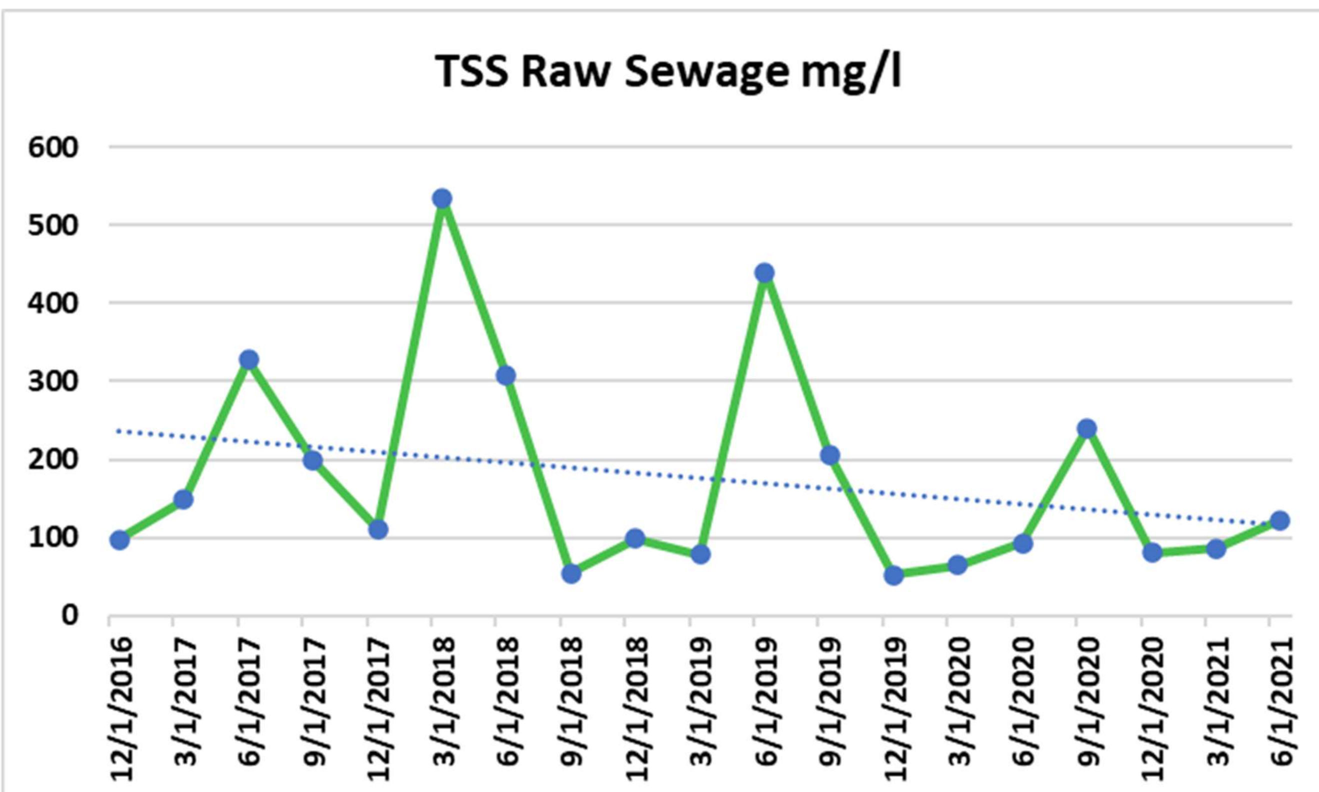
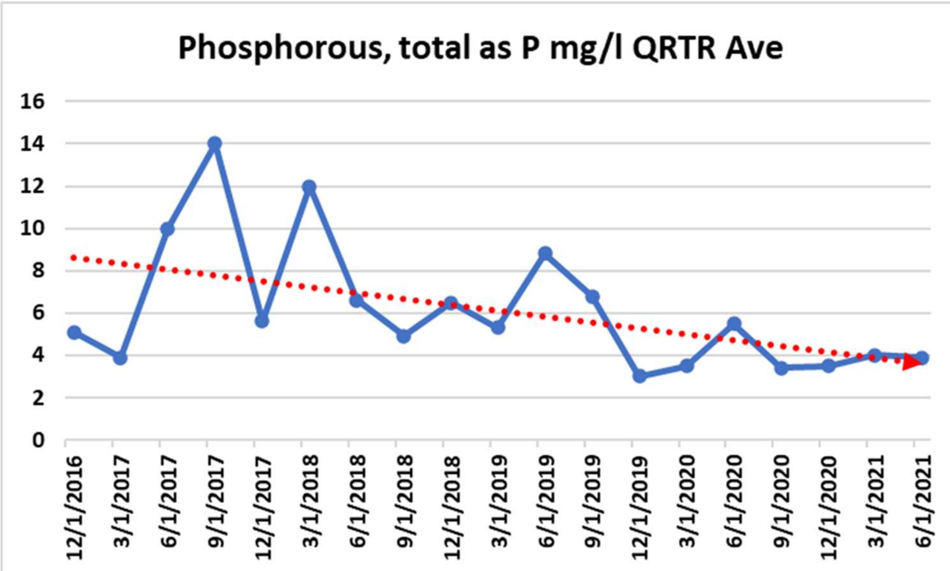
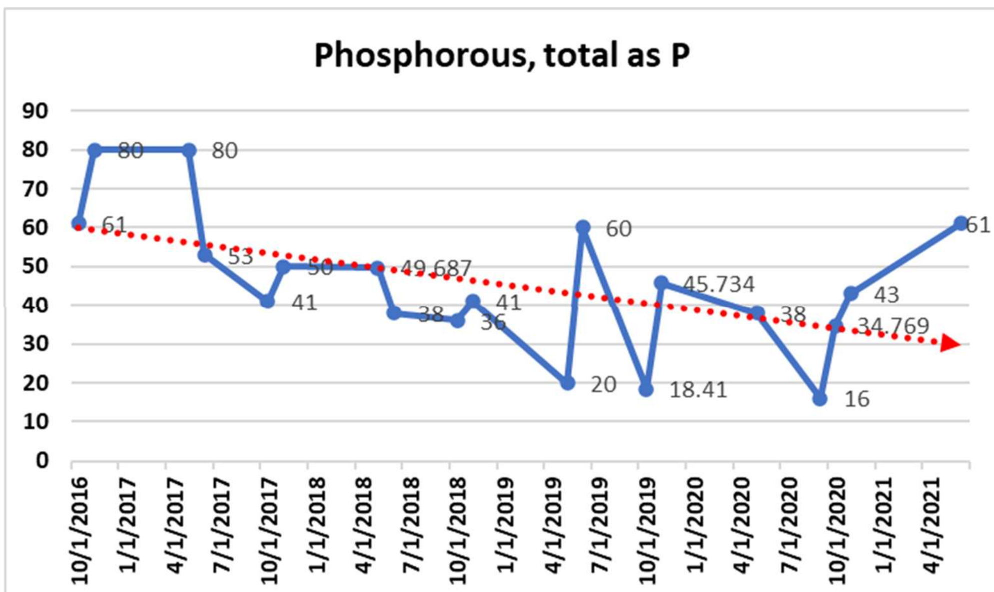


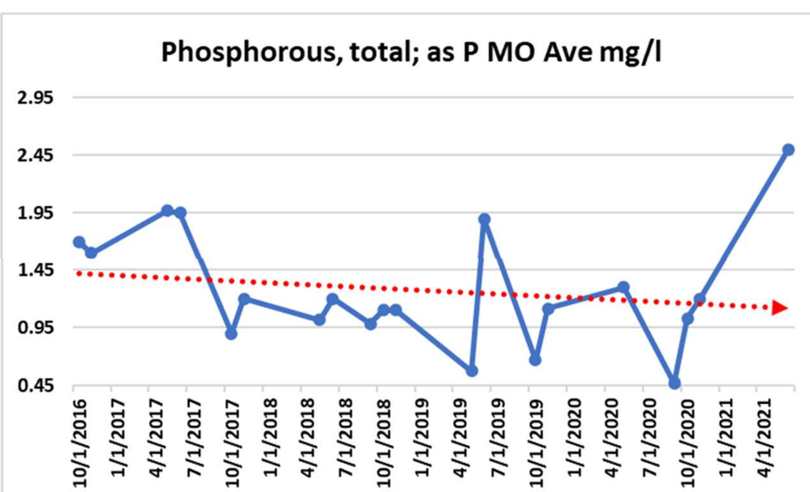
Figure 21. Influent TSS Trending Down

Section 4 – DMR Data Analysis Cont-



Figures 22, 23, 24 All Measures of Phosphorous are Trending Down





Section 4 – DMR Data Analysis Cont-

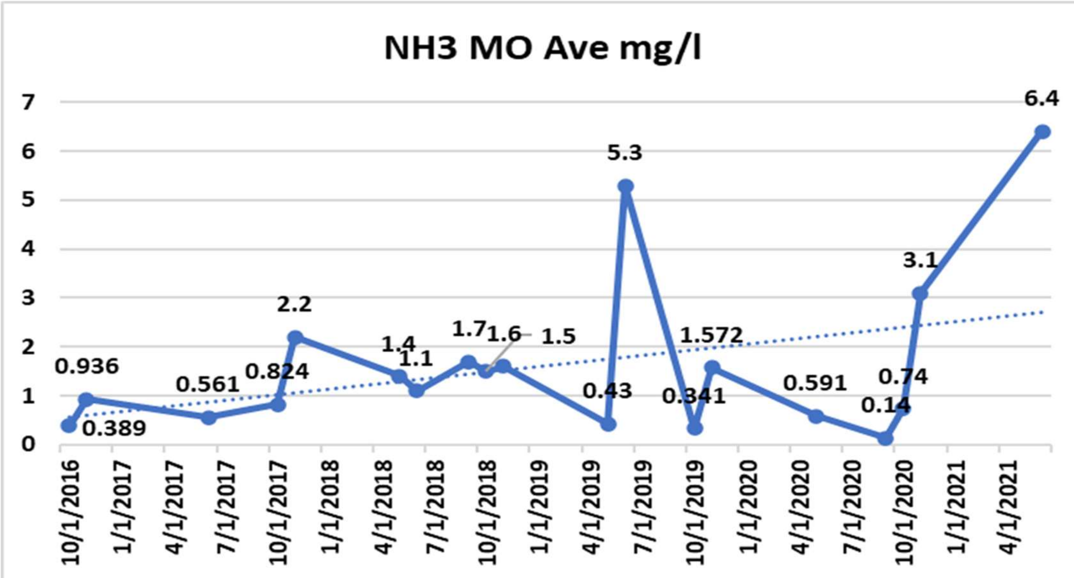


Figure 25. Effluent Ammonia is Trending Up. If Ammonia and Nitrifying Bacteria Get Into the BOD_5 Test Bottle, it will Inflate the Result

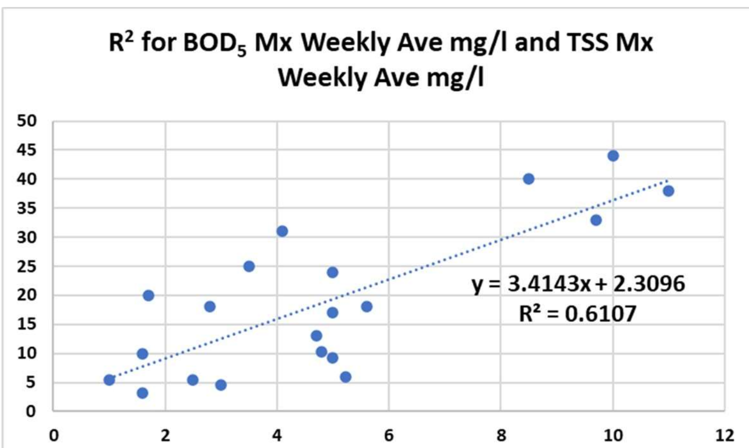
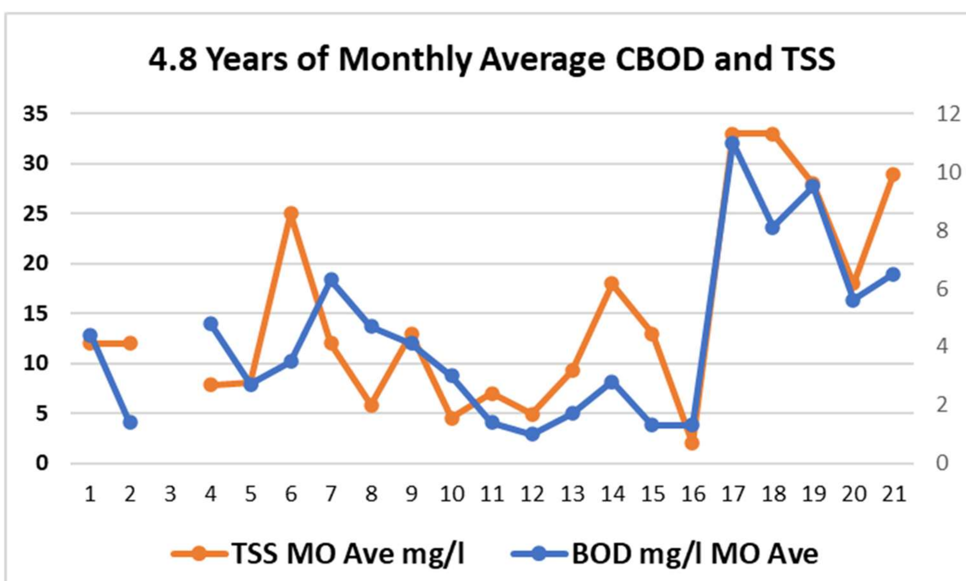


Figure 26 & 27. A Close Relationship Exists Between TSS and BOD Such That Lowering TSS will Lower BOD



Section 4 – DMR Data Analysis Cont-

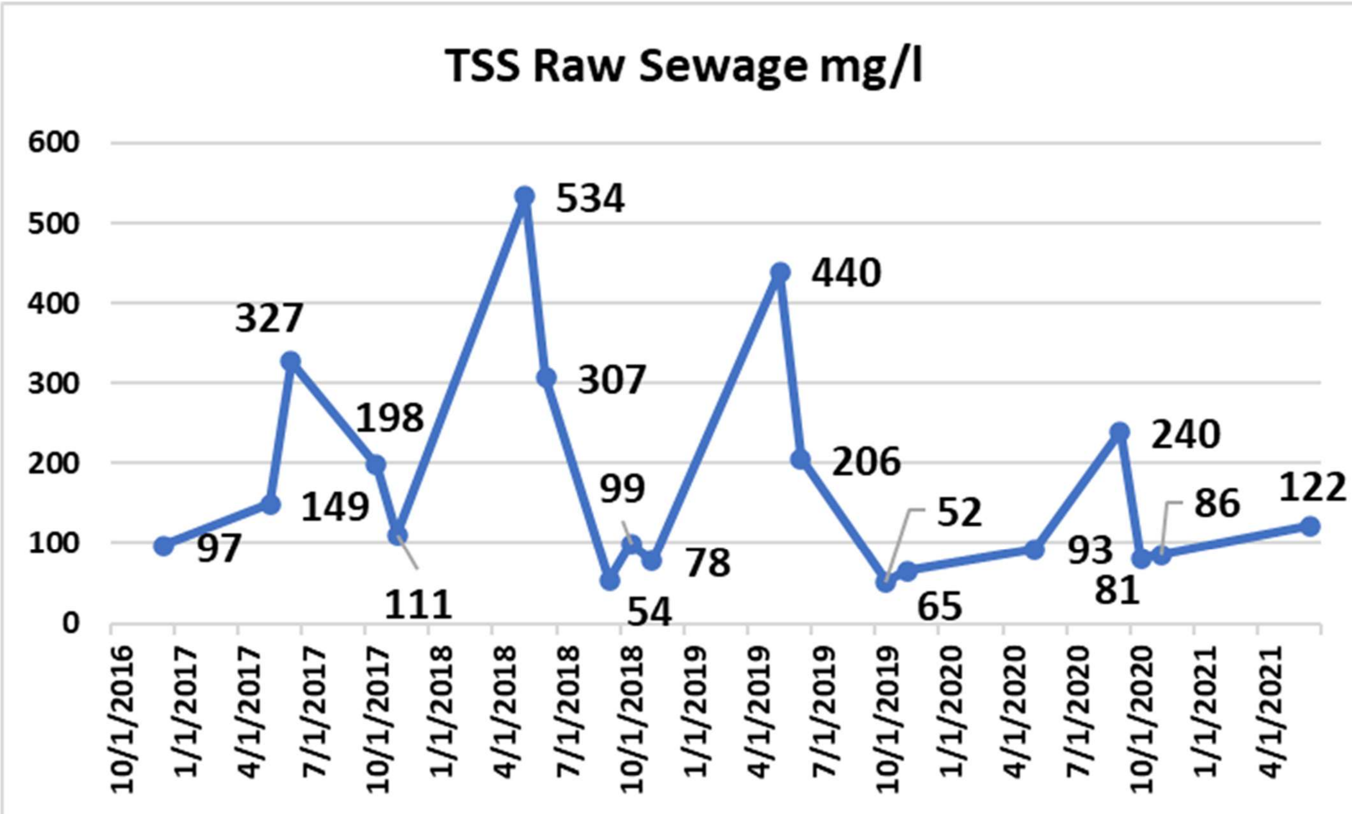


Figure 28. Raw Sewage Trending Down

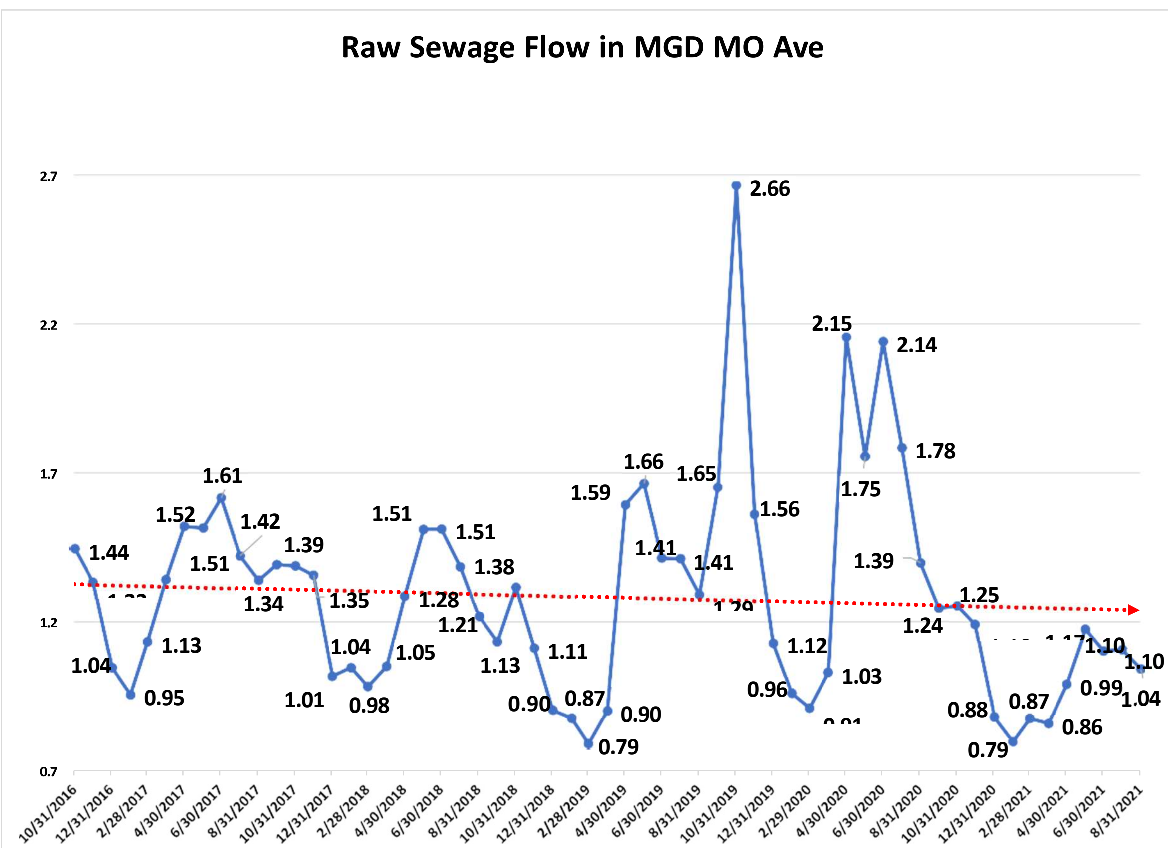


Figure 29. Monthly Average Flow Over Four Years

Section 4 – DMR Data Analysis Cont-

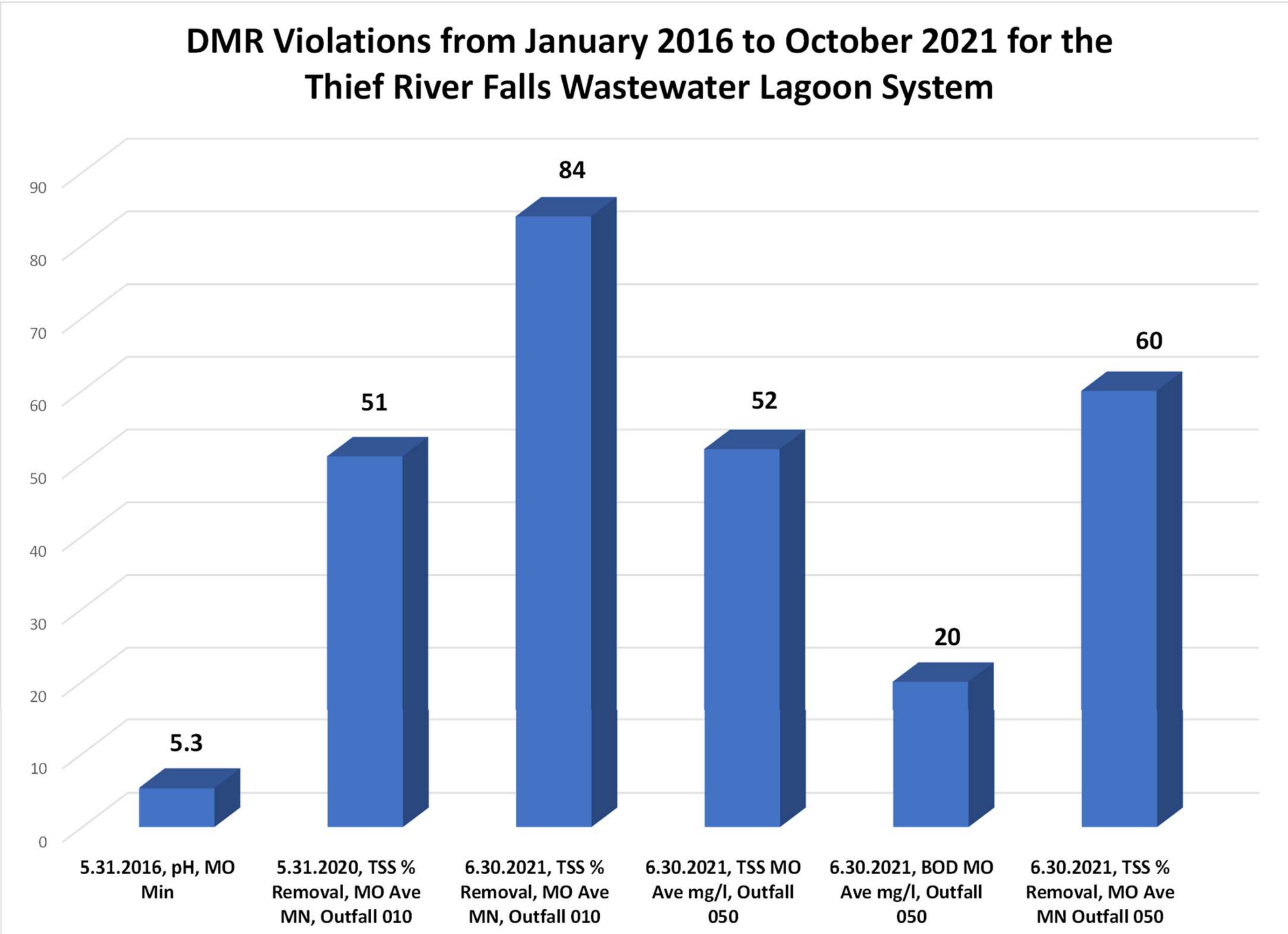


Figure 30. Exceedances by Type and Date

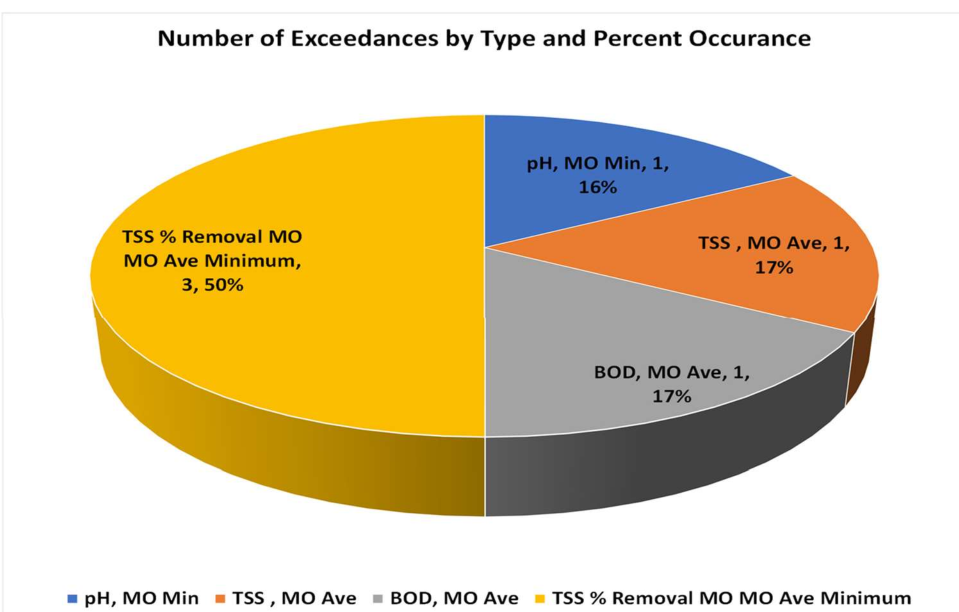


Figure 31. Exceedances by Type, Number, and Percentage of Occurrence

Section 5 – Summary

Thief River Falls Minnesota wastewater pond system typically meets permit limits because it holds water long enough to exhaust the nutrients causing typical permit limit violations. Fifty (50) percent of Thief River Falls permit violations are for Percent Removal violations; the collection system delivers a dilute influent in terms of concentration. Many of the best upgrades for a lagoon system are made in the collection system.

At the time of field testing, all limits were within permitted limits except for pH. To keep within permit limits, discharge as few algae cells as possible and no ammonia.

Recirculating highly oxygenated water from Cell # 2 or 3 in the afternoons to Cell # 1 would help keep the system odor-free and improve water quality overall. Removing the sludge from Cell # 1 should be planned for in the next five (5) to seven (7) years. Desludge Cell # 1 when TSS removal efficiency consistently begins to drop below 85%.

Section 6 – Action Items

The recommendations outlined in this report offer solutions for meeting permit limits in a long-term sustainable fashion.

Five (5) Action Items are recommended for the Thief River Falls Minnesota wastewater lagoon system, and they are:

1) Tighten the collection system to reduce dilute influent TSS and $CBOD_5$ or pull influent samples more frequently to improve influent numbers.
2) Plan to desludge Cell # 1 in the next five (5) years
3) Closely monitor the trends in water quality permit parameters. When they get close to permit limits it is time to deslude
4) Recirculate water high in Dissolved Oxygen from Cell # 2 or Cell # 3 to Cell # 1 for odor control and improved water quality.
5) Quarterly perform intra-pond diagnostic BOD, Ammonia, and Nitrate sampling between each treatment cell to understand the nature of the system.

Section 7 – Conclusions

CONCLUSIONS

The Thief River Falls wastewater lagoon system is run by a competent crew doing a fine job in keeping the system within permit limitations. The pond system is healthy and is generally working well.

There is a ***where,*** **a *when,* and a *why*** to lagoon problem solving and optimization. Determining where treatment is not occurring is essential to optimizing Thief River Falls, Minnesota's wastewater lagoon system for continued sustainable permit compliance.

Please see Diagnostic BODs in the attachments and commit to routinely performing these kinds of tests.

Section 7 – Conclusions-Continued

Thank you for the opportunity to serve the good people of Thief River Falls, Montana.

Steve Harris
President

H&S Environmental, LLC

Attachments

1) Diagnostic BODs
2) Algae’s Contribution to the BOD_5 Test Result
3) The Importance of Mixing Lagoon Sludge Blankets

References

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Algae's Influence on the BOD_5 Test

Steve Harris, President, H & S Environmental, LLC

Algae…you both love it and hate it. You love algae because they add dissolved oxygen to your system through photosynthesis. This leads to BOD removal, better ammonia removal, pathogen kill, and odor control. This is the upside of having algae in your pond system.

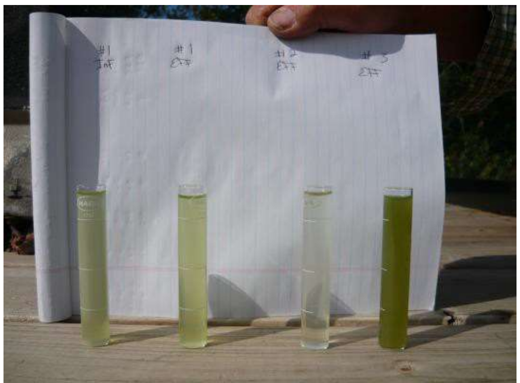

Figure 2. Algae Concentrations Vary from One Cell to Another. This Will Change Water Quality Photo

You hate it because algae create TSS and BOD violations as well pH problems. TSS violations caused by algae are well understood, but algae's contribution to BOD violations requires explanation. When the lights are on algae create oxygen. When lights are off algae no longer create oxygen, but consume it in a process called respiration. This is why measuring dissolved oxygen before sunrise is so important. For twelve (12) hours or so algae have been consuming oxygen at night under dark conditions instead of producing it. The bacteria and protozoa in the system consume oxygen 24/7, algae 12 hrs. When the sunlight returns algae begin once again to make oxygen to add to the water column.

Figure 1. TSS Filter. Effluent TSS 105 mg/l Courtesy of Mark Court, Wyoming Rural Water

Figure 3. Effluent from Each Cell in the System and the Chlorine Contact Chamber

Imagine dark conditions over your lagoon for five (5) consecutive days! What would happen to your DO? Now think about what happens to your effluent sample during the BOD_5 test. Under the darkened conditions of the BOD_5 test, algae consume oxygen for five (5) days instead of producing it. Along with bacteria, dead and decaying algae cells can also add directly to BOD in the test bottle by releasing the material that was once bound up in their cellsTo determine algae's influence on the BOD_5 test, algae are filtered out of one of the samples in a split sample. The BOD test is run on both samples of the same sample and the two are compared. The results can bedramatic. The following certificate shows a worst-case scenario from a lagoon system in a rural community…a system probably much like your own.

BSK ASSOCIATES

A6I2745

General Chemistry

BOD Reduction

Certificate of Analysis

Sample ID: A6I2745-01
Sampled By: [redacted]
Sample Description: Headworks

Sample Date - Time: 09/22/16 - 13:00
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand	SM 5210B	**300**	50	mg/L	50	A613004	09/23/16 16:33	09/28/16	

300 mg/L

Sample ID: A6I2745-02
Sampled By: [redacted]
Sample Description: Pond 1 in

Sample Date - Time: 09/22/16 - 13:03
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand	SM 5210B	**63**	15	mg/L	15	A613004	09/23/16 16:35	09/28/16	

63 mg/L

Sample ID: A6I2745-03
Sampled By: [redacted]
Sample Description: Pond 1 out

Sample Date - Time: 09/22/16 - 13:05
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand	SM 5210B	**54**	10	mg/L	10	A613004	09/23/16 16:37	09/28/16	

54 mg/L

Sample ID: A6I2745-04
Sampled By: [redacted]
Sample Description: Pond 2 out

Sample Date - Time: 09/22/16 - 13:10
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand	SM 5210B	**130**	30	mg/L	30	A613004	09/23/16 16:39	09/28/16	

130 mg/L

Sample ID: A6I2745-05
Sampled By: [redacted]
Sample Description: Pond 3 Discharge

Sample Date - Time: 09/22/16 - 13:15
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand	SM 5210B	**100**	15	mg/L	15	A613004	09/23/16 16:41	09/28/16	

100 mg/L

Sample ID: A6I2745-06
Sampled By: [redacted]
Sample Description: Pond 3 Discharge

Sample Date - Time: 09/22/16 - 13:15
Matrix: Waste Water
Sample Type: Grab

BSK Associates Fresno

General Chemistry

Analyte	Method	Result	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Biochemical Oxygen Demand - Dissolved (1)	SM 5210B	**6.0**	4.0	mg/L	4	A613004	09/23/16 16:43	09/28/16	

6 mg/L

In this system, on this day, a full 94 mg/l of BOD was caused by the presence of algae in the effluent of this lagoon system. The Dissolved Biological Oxygen Demand (filtered BOD) is the BOD without the algae present. This system had to report effluent BOD of 100 mg/l on their DMR.

So, what does this mean for all of us operating lagoon systems? Discharge as few algae cells as possible! This can successfully be accomplished by 1) discharging your effluent from a few feet below the surface of your pond's surface or 2) using a sand filter. The newest EPA lagoon manual (EPA/600/R-11/088 | August 2011 | www.epa.gov /nrmrl) shows just how successful sand filters can be at lowering not only TSS but BOD as well. (See Chapter 7)

Figure 4. Algae and sludge Can Both Leave the Pond System to Affect BOD

Sand filters of all types have proven themselves effective at polishing wastewater pond system effluents to very low levels of BOD and TSS. Serious consideration should be given by any lagoon system faced with building an activated sludge plant, to polishing their lagoon effluent using some sort of sand filtration. This alternative will allow you to keep your lagoon system while minimizing upgrade costs to maintain permit compliance.

Figure 5. Pulling the Water Below Three (3) Feet Will Generally Result in Fewer Algae Cells Being Discharged

Because algae need sunlight, their concentrations are typically highest in the upper three (3) feet of a pond's surface. Pulling water from below this "photic zone" helps to minimize the discharge of algae cells.

In deeper treatment cells this is a smart upgrade.

- Sludge Removal
- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization

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Diagnostic BODs and TSS

BOD is composed of two components; Carbonaceous BOD and Nitrogenous BOD. Carbonaceous BOD is the result of the oxidation of carbon. Nitrogenous BOD is the oxidation of ammonia to nitrate.

$$BOD_5 = CBOD_5 + NBOD_5$$

The oxidation of ammonia to nitrate requires a great deal of oxygen as seen in the formula below:

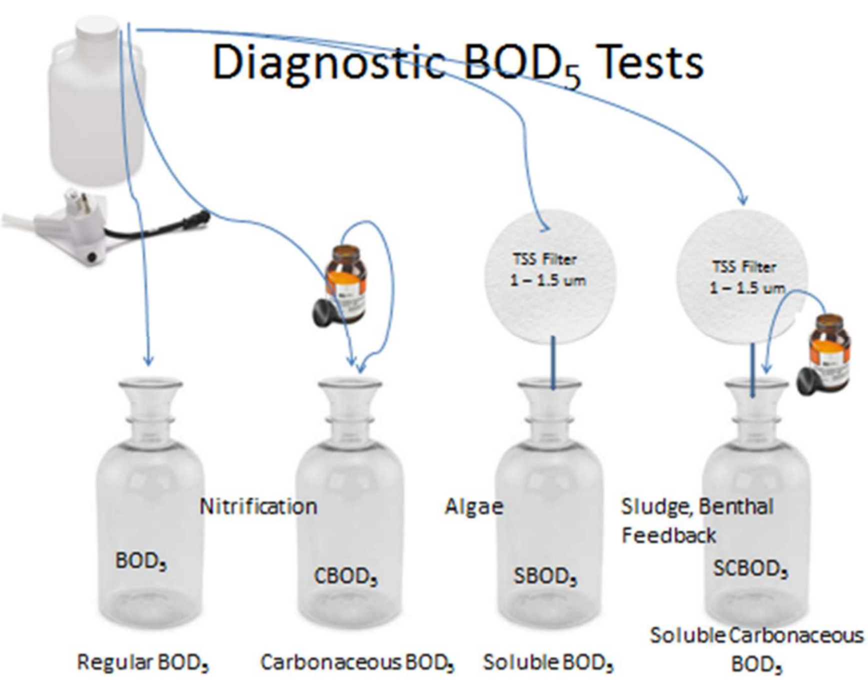
$$NH_3 + 2O_2 \longrightarrow NO_3^- + H^+ + H_2O$$

The oxygen requirement for nitrification is:

4.6 mg O2/l mg NH4+ - N oxidized to NO3- (U.S. EPA, 1975)

You can see that a great deal of oxygen is required to convert ammonia to nitrate--- much more oxygen than is required to convert carbon to its end products: 1 mg of the organic fraction of biomass exerts an oxygen demand of 1.42 mg (WEF, 1994)

The problem with the BOD test is that ammonia, algae, and sludge can have a profound influence on the test results. Determining which one of these influences is the exact cause of the high BODs will help identify a specific solution to lowering the effluent BOD.

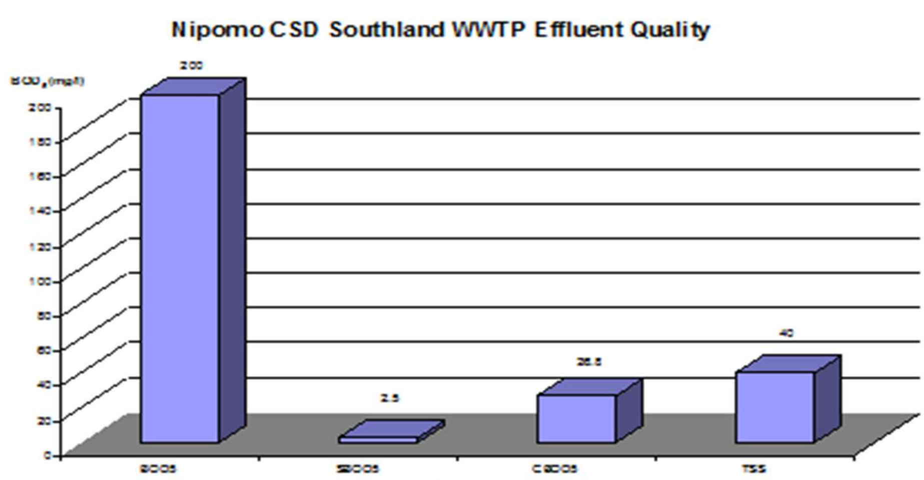


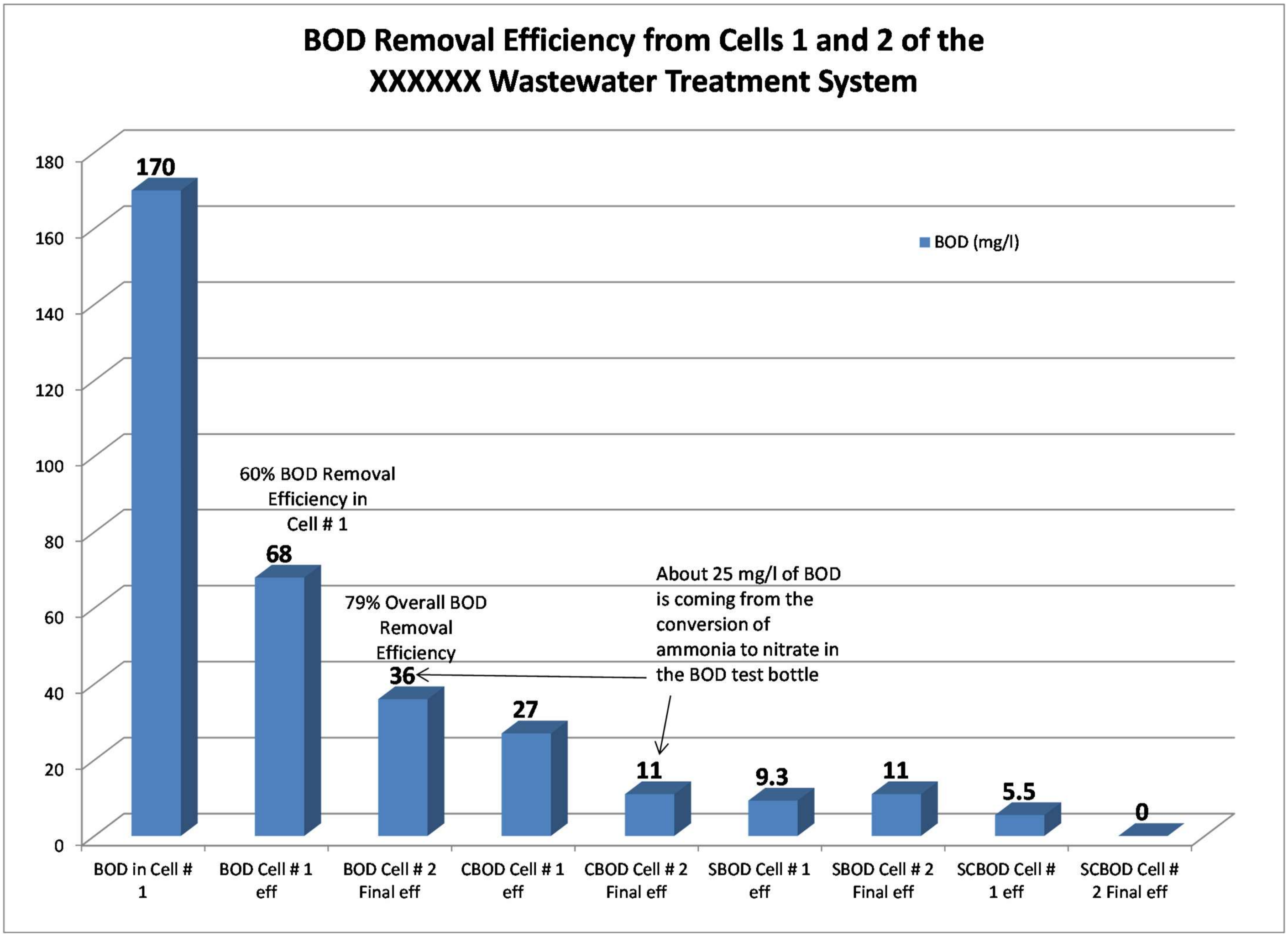
Failing to understand the source and cause of the BOD is to potentially apply the wrong solution to achieving 10/15s. waste both time and money on a solution that may yield few results toward a 10/15 solution.

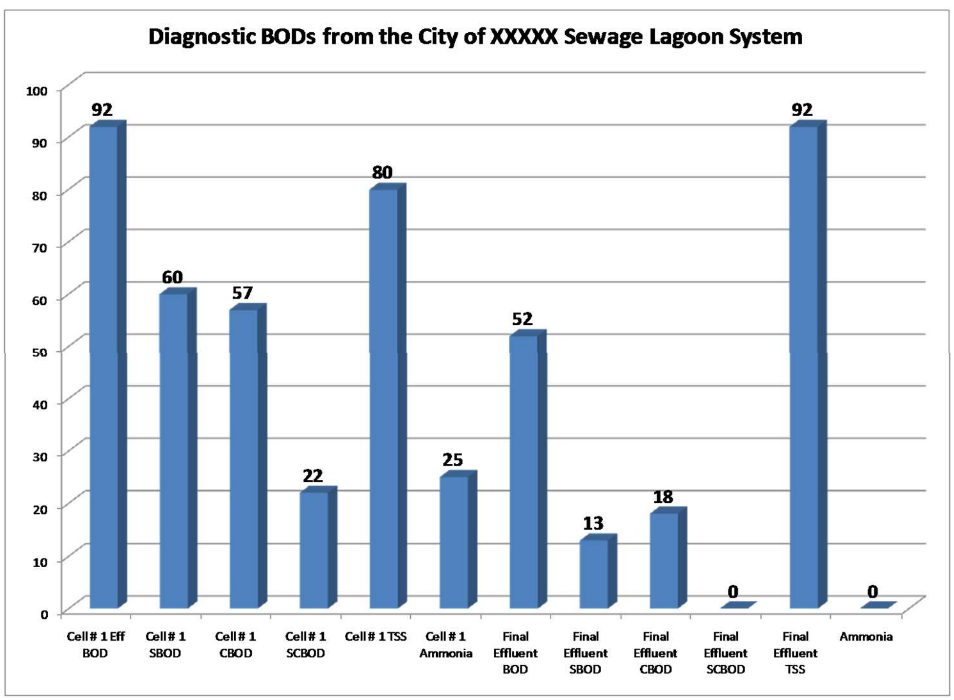
- $\underline{BOD_5}$ $\underline{\text{Regular Five Day BOD}_5}$ A standard used to measure the strength of wastewater.

  $BOD_5 = CBOD_5 + NBOD_5$ Used as a standard. Also used as a testing starting point to understand more about what is going on in a lagoon. A BOD is needed to calculate $NBOD_5$; an indication of a lagoon's ability to nitrify.
- $\underline{\text{SBOD5/Filtered BOD}_5}$. Also called a Soluble BOD_5. The BOD_5 test sample is first run through a filter. Measures the most readily oxidizeable portion of the wastewater sample. $SBOD_5 = SCBOD_5 + SNBOD_5$ Rich, (1999) needed to calculate $SCBOD_5$ "- it is unusual to see $SBOD_5$ in the effluent greater than 20% of the total". Richard & Bowman (1991)
- $\underline{CBOD_5}$ $\underline{\text{Carbonaceous Biological Demand}}$. The BOD_5 test run with a nitrification suppressant added to inhibit nitrification's effect on dissolved oxygen in the BOD_5 test bottle. $CBOD_5 = BOD_5 - NBOD_5$ A better measure of a lagoon's ability to stabilize waste.
- $\underline{NBOD_5 = BOD_5 - CBOD_5}$ = The relative number of nitrifying bacteria in the BOD test bottle. Rich (1999)
- $\underline{SCBOD_5}$ $\underline{\text{:Soluble Carbonaceous BOD}_5}$ The BOD_5 test run after it is filtered and the nitrification suppressant is added. The influence of a lagoon's sludge blanket in feeding BOD back to the water column. Also used with $CBOD_5$ to determine algae's effect on the BOD_5 test: ($PBOD_5$)
- $\underline{PBOD_5 = CBOD_5 - SCBOD_5}$ A PBOD > 70% of the BOD_5 in the effluent indicates a solids

Diagnostic BODs Tell Us ***Why*** the Problem is Occurring



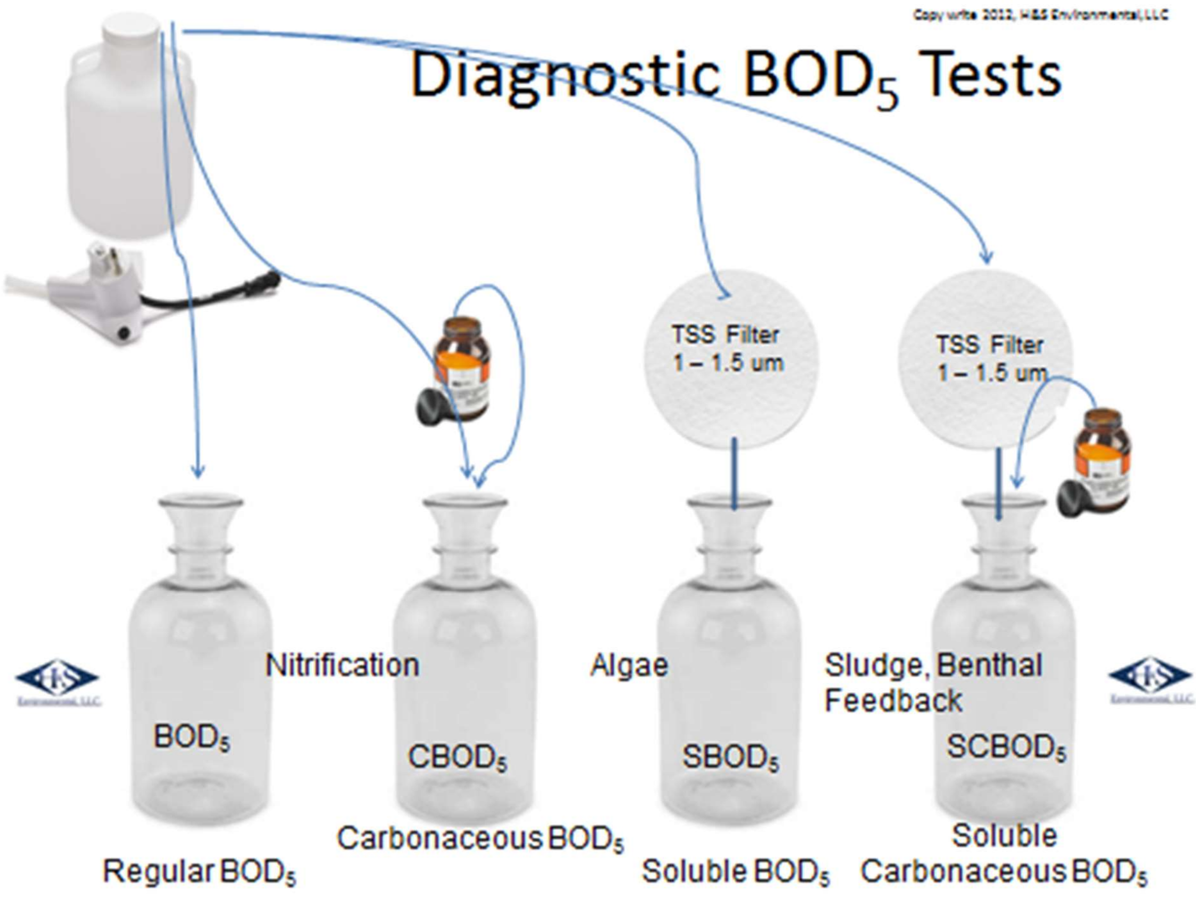

BOD Removal Efficiency from Cells 1 and 2 of the XXXXXX Wastewater Treatment System
BOD (mg/l)
0
20
40
60
80
100
120
140
160
180
170
68
36
27
11
9.3
11
5.5
0
60% BOD Removal Efficiency in Cell # 1
79% Overall BOD Removal Efficiency
About 25 mg/l of BOD is coming from the conversion of ammonia to nitrate in the BOD test bottle
BOD in Cell # 1
BOD Cell # 1 eff
BOD Cell # 2 Final eff
CBOD Cell # 1 eff
CBOD Cell # 2 Final eff
SBOD Cell # 1 eff
SBOD Cell # 2 Final eff
SCBOD Cell # 1 eff
SCBOD Cell # 2 Final eff


Diagnostic BODs from the City of XXXXX Sewage Lagoon System
0
10
20
30
40
50
60
70
80
90
100
92
60
57
22
80
25
52
13
18
0
92
0
Cell # 1 Eff BOD
Cell # 1 SBOD
Cell # 1 CBOD
Cell # 1 SCBOD
Cell # 1 TSS
Cell # 1 Ammonia
Final Effluent BOD
Final Effluent SBOD
Final Effluent CBOD
Final Effluent SCBOD
Final Effluent TSS
Ammonia

<u>What are the BOD_5 and $CBOD_5$ coming into and out of *each* cell?</u>

Intra-Pond Testing

A primary treatment cell should be removing between 60 to 80% of a pond's influent BOD. If not, then determine why. For solving BOD problems there is a ***where*** the BOD problem is occurring and ***why*** a BOD problem is occurring and ***when*** it is occurring. Run a series of diagnostic BODs **<u>between each</u>** pond to determine the cause of a BOD problem. Because of the influence of accumulated sludge, algae, and/or nitrification in the BOD test bottle, one of the ponds may be **<u>adding</u>** BOD back to the system. Isolate the cause and location and timing of the BOD problem to effectively reduce effluent BOD.



Diagnostic BODs are not something you do every week or each month but several times a year to identify the cause or the WHY of the elevated BOD. All this takes the guess work out by knowing why the problem is occurring and then take measures to solve the problem.

The same type of thing can be done with the TSS test. Have the lab take the filter used in the TSS test and look at it under the microscope. Look for black spots indicating sludge particles leaving with the effluent. Look for bacteria floc, or anything else unusual leaving with the effluent. High TSS could be caused by a rotifer or *daphnia* bloom. It could be caused by sludge particles leaving with the effluent. You will never know until you look.

Know what types of solids are leaving with the lagoon effluent.

Each type of solid material leaving a lagoon has a meaning. Sludge particles leaving with a lagoon effluent mean it may be time to desludge or raise the effluent discharge pipe. The presence of filamentous bacteria may be evidence of the need to add more air or reduce the loading to the lagoon system. Certain other type of filaments may indicate excessive oils or grease in the system. Sometimes a rotifer or ***daphnia*** bloom may get out with the effluent and be picked up as TSS. Ask your lab to identify the types of solids leaving your pond system.

A Volatile Suspended Solids (VSS) test will help further determine if the TSS sample is composed mostly of algae or nonvolatile material. Low VSS indicates the presence of sludge solids, grit, gravel, etc.

Steve Harris
President
H&S Environmental, LLC

Duckweed in Wastewater Pond Systems

Steve Harris, H&S Environmental, LLC | Gary Webber, MRWA Wastewater Technician

Like algae and sludge in a wastewater pond system, duckweed can have both good and ill effects on effluent water quality. Duckweed cover works best when managed. Below are some listed advantages and disadvantages:

Disadvantages

1) Duckweed leads to sludge accumulation if left in the pond system un-harvested
2) Dead duckweed can release ammonia and other nutrients if allowed to die, settle to the pond bottom, and decay
3) A duckweed cover can cause odors by suppressing dissolved oxygen production normally provided by algae
4) A duckweed cover leads to poor pathogen destruction because it blocks ultra-violet light (UVB) from the sun
5) Duckweed cover suppresses oxygen production because it limits algae population and keeps pH low, absence of oxygen is presence of carbon dioxide (CO_2). Carbon dioxide suppresses pH
6) Particles from dead and decaying duckweed can lead to total suspended solids (TSS) issues
7) Duckweed prevents atmospheric reaeration resulting in low dissolved oxygen (DO)
8) Without sunlight, algae are prevented from growing. Algae regulate pH and DO in pond systems. Both are essential for odor control and pathogen removal
9) Duckweed can prevent water from evaporating
10) A thick duckweed cover can trap CO_2 causing CO_2 accumulation resulting in low pH

Advantages

1. Nutrients are removed when duckweed is harvested. Duckweed covered ponds tend to have lower Total Nitrogen and Phosphorous in the effluent
2. TSS is controlled by stifling algae growth
3. BOD is reduced because algae growth is controlled
4. pH is also controlled and reduces chance of exceeding the permits high pH limit
5. Duckweed root hairs and surfaces exposed to water can provide an attachment site for nitrifying and purple sulfur bacteria
6. Duckweed has been shown to add O_2 to the very surface of the treatment cell supplying oxygen for nitrifying bacteria and facilitating the oxidation of hydrogen sulfide (H_2S). The authors have measured up to three (3) mg/l of DO in the very upper surface of a duckweed covered treatment cell.
7. Phosphorous removal if harvested

Probably the greatest benefit of a duckweed cover is its ability to suppress algae growth leading to TSS, BOD, and pH compliance. Because algae consume oxygen for five (5) days while in the BOD_5 test bottle, algae inflate effluent BOD_5 numbers. Filter the algae out before a BOD_5 test is run and notice just how low the BOD becomes; reduced algae result in BOD_5 and TSS control. Algal fractions of pond effluent BOD_5 are known to be anywhere between 60 and 90% of the total BOD_5, especially during summer. Because algae consume CO_2 and affect the bicarbonate cycle, pH is elevated by the presence of algae. Reduce the algae with a duckweed cover and the pH drops.

The disadvantage of a duckweed cover is that it suppresses DO production and keeps pH low. These two things coupled with blocking UVB from the sun lead to pathogen control problems in the effluent. If there is no UV or chlorine disinfection, a duckweed cover may be problematic.

Management techniques do exist for duckweed control. Ideally, in a multi-celled pond system, a thick duckweed cover would be confined to the latter cell or the latter part of the final cell to control algae growth and keep pH within limits. Duckweed populations double every 2 to 4 days, so a combination of control methods may be best. As in all things related to wastewater lagoon systems, duckweed control is best achieved by wastewater operators trying different strategies and seeing what works best and then fine-tuning those strategies. Let us now look at some control methods.

Mechanical Control

Mechanical control consists of a trash pump or submersible pump, window screen, and expanded steel to support the window screen. The suction end of the trash pump floats on the surface of the pond using sealed plastic jugs or other floatation devices. The discharge end of the pump flows over a piece of expanded steel with window screen covering it. The window screen/expanded steel piece is placed over a culvert or drum with a hole cut into the bottom and placed on the dike to allow the water to flow back into the treatment cell. The expanded steel/window screen piece must occasionally be lifted and shaken to remove the accumulated duckweed to a pile. If duckweed populations double every 2 to 4 days, then mechanical removal should occur at least weekly. After removal, duckweed is now a wastewater byproduct and must be handled as such. Follow all state rules for disposal just as you would with headworks trash.

Chemical Control

Several good chemicals exist for the treatment and control of duckweed covers. **Sonar AS** or **Sonar RTU** by Sepro Corporation is an excellent and proven chemistry for duckweed control. **ALLIGARE Fluridone** is another chemical proven to reduce or remove duckweed. Several other chemistries also exist to control duckweed, but it is always a good practice to use a licensed herbicide applicator in the selection and application of aquatic herbicides. This is especially true for those systems discharging into sensitive waterways. Some residual may exist after application and treatment that may affect aquatic life in the receiving waters downstream. If possible, hold water for as long as possible before discharge after application. Be aware that aggressively killing duckweed may cause an increase in BOD, TSS, and/or ammonia as the duckweed dies and its cells rupture. Chemical control will typically remove ALL the duckweed from each treatment cell, so duckweed's positive benefits will not be realized. With chemical control, it is best to stay ahead of the bloom to use less chemical. Adding chemical after a bloom has set in may not be an efficient use of labor and chemical. Treat at the first signs of a duckweed bloom but don't wait too long!

Biological Control

Some operators report that the addition of bacteria may help in the control of duckweed. It is the authors' opinion that if bacteria products are used, get a guarantee and make sure everyone involved knows what successful control means and how success will be measured. Include the time frame it will take for control. Grass Carp feed on duckweed but their effectiveness is difficult to predict because they can feed on things other than duckweed. A duckweed control strategy using grass carp is best used if local Game and Fish is consulted because striking a balance between duckweed concentrations and grass carp populations requires knowledge of grass carp behavior. If Grass Carp are used it is important to follow the rules the state has set forth for the introduction of fish into wastewater pond systems. The US Forest Service uses triploid grass carp for duckweed control. Triploid grass carp can control duckweed and other aquatic plants by eating them. Triploid carp cannot multiply but will live for 8 or more years and grow to 30 pounds or more if they get enough to eat. The carp are voracious and may eat the plants faster than the plants can regrow.

Duckweed Challenges

Duckweed presence in lagoon treatment ponds truly create operational and compliance challenges for wastewater operators. Utilities that have adequate time and manpower can manage duckweed to compliment the treatment system. However, many small communities do not have the staff, equipment, and luxury of time to devote to controlling duckweed population and presence. Lagoon effluent draw-off structures can be utilized to reduce or eliminate duckweed wasting to the outfall which is the location used for monitoring compliance and water quality tracking.
However, many of these draw-off structures are un-operable due to age or lack of maintenance and many lagoon systems were never equipped with flexible or manageable draw-off capabilities. Thus, wasting of duckweed to the outfall will lead to increased TSS, BOD, ammonia, phosphorous and total nitrogen in compliance samples.

What does duckweed like?

Duckweed favors nutrient rich environments. So, if the influent wastewater has high nutrient levels it will encourage duckweed growth. Tracking influent concentrations of BOD, ammonia, phosphorous and total nitrogen help determine if someone is dumping elevated waste concentrations into the collection system. Bad behavior in the collection system can be tracked down and solved most of the time with extra sampling, composite samplers, and a little common sense and luck. Other factors that encourage duckweed presence is tall grass around berms, unkept berms, weed presence in the inside slope of the berm, or weeds in the pond itself all limit wave action therefore duckweed can flourish. Many lagoons have been built in low-lying areas and allow for little wind-sweep on the lagoon pool. Trees and brush growth in fence rows (anything that blocks wind-sweep) will help provide promising environments for duckweed to grow. Wind- sweep is paramount for healthy lagoon biochemistry functions. When wind-sweep is not or cannot be achieved, artificial mixing and aeration is needed.

Excessive sludge accumulated in the pond cell definitely increases the likelihood of duckweed problems. The life cycle of duckweed living, up-taking nutrients, growing bio-mass and increasing populations, dying and returning to the bottom of the lagoon cell only increases sludge volumes over time. In a nutshell, un-managed duckweed presence creates a snowball effect of sludge volumes and nutrient banking.

Lagoon System Case Study Middletown, MO

Duckweed was present as a thick mat over the surface of 3 lagoon cells. Samples were taken from primary cell September 2019 and analyzed in a laboratory-controlled environment over a five-week period. The original total phosphorous (TP) was 15.4 ppm, after one-week in control conditions TP was 17.7 ppm and then continued in weekly analysis to drop to 13.4 ppm over 5 weeks. While total nitrogen (TN) initial analysis was 22.6 ppm, on week 2 TN spiked to 37.4 ppm, and after 5 weeks the TN fell to 21.3 ppm. This laboratory study was performed to identify if duckweed releases nutrients when cell structure breaks down. The H_2O Solution of Marceline, MO provided laboratory analysis and quality control of samples.

When samples were filtered, the average TP was 10.78 ppm and the average for filtered TN was 13.60 ppm. The percentage of removal for filtering duckweed and other debris from the TP samples was 30%, where the percentage of removal of TN by filtering samples was 47%, showing evidence of nutrient capture within the duckweed cell structure.

April 2020 sampling – Following no visible duckweed through late fall and winter months, TP was 5.02 ppm and TN was
8.25 ppm.

Middletown made the decision to remove the duckweed via application of **Sonar AS**. The lagoon had previously been drawn down by normal controlled discharge and the effluent valve was closed. Pond dye was utilized as a shading mechanism in days leading up to the application. On May 1, 2020, the application in all three lagoon cells was conducted by staff, administration, and MRWA Wastewater Technician. At this time there was approximately 30% duckweed cover in the primary cell and moderate presence in cell #3. The application of the product was administered in the evening hours prior to nightfall as **Sonar AS** effectiveness is negatively influenced by sunshine. By June 8, 2020, the cells were almost total open water and duckweed all but eliminated. By October 2020, Middletown's lagoon cells were returned to a normal productive treatment process. However, this lagoon went through a very difficult time recovering from the removal of a dominant species after the duckweed was killed. Process problems arose almost weekly with algae mats, scum, and bad behavior algae attempting to become the new dominant species. The staff and administration proactively combatted these process problems in various ways while waiting on the lagoon to balance itself over time.

Middletown Lagoon cell "Before"

Middletown Lagoon cell "After"

H&S Environmental, LLC.

How to Sludge Judge a Lagoon

Figure 1. A Two (2) inch Sludge Judge

Before you begin, first measure your lagoon's dimensions. Next, go to Google Earth and take a satellite picture of your lagoon system. Paste the picture of each cell individually onto a sheet of paper and divide the cells into quadrants using a grid of uniform length and width like the one seen in ***Figure 2***.

Make sure you have at least 24 to 36 sample points on your grid. Remember you are not confined to the grid once you are out there in the boat. You will want to take extra samples and measurements at the influent and effluent areas and corners of the cells. You will typically record water and sludge depths directly onto the grid you make.

After you have made your paper grid, it's time to go to your lagoon system and make the real grid on the pond dikes themselves using fluorescent marking paint, stakes, cones, flagging, or anything else you can think of that will be clearly visible from the boat you will be in.

Ideally you will have someone navigating the boat, another sludge judging and core sampling, and two others on the dikes helping you get lined up at the intersections of the length and width grid marks.

Figure 2. A Sludge Judging Grid Created from a Satellite Image

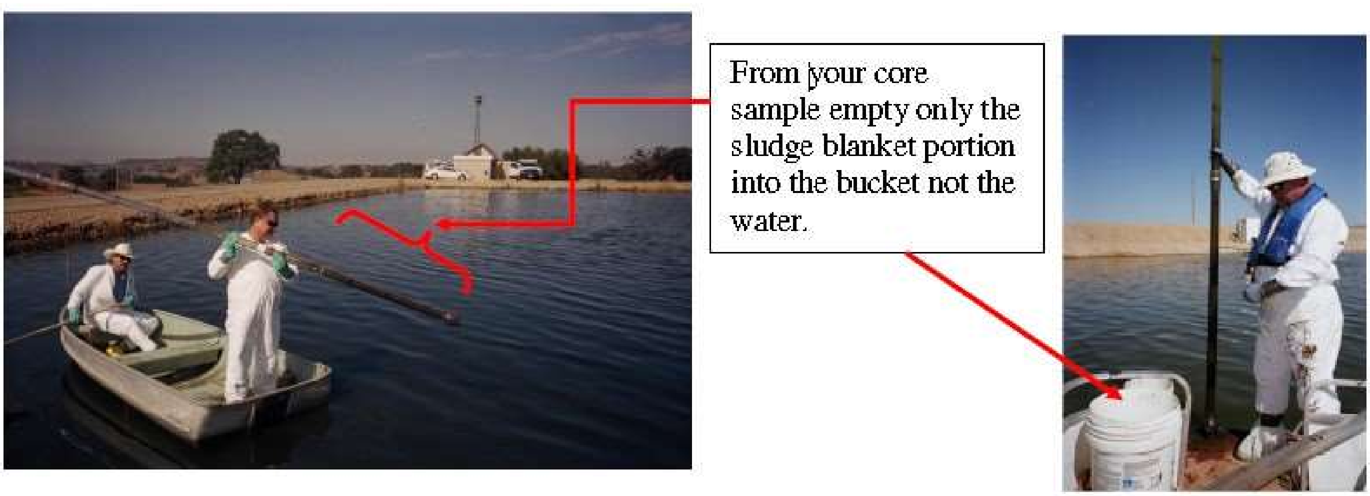
Figure 3. Grid Created on the Cell with Stakes and Paint

Figure 5. Water Resources Management Sludge Judging a Pond System

Figure 4. A 2" Clear Foot Valve

The bigger the sludge judge the better. We use a 2” sludge judge we made ourselves using 2” clear Schedule 40 PVC and a clear 2” standard plumbing flap foot valve. The foot valve does not necessarily need to be clear so to save money you can use a white 2” PVC foot valve available at most plumbing supply stores. To help you better see the sludge and water depths, you should use clear male and female adaptors if you will be cutting the clear plastic pipe into five-foot (5’) sections. Mark the clear pipe using a waterproof marker and/or tape. Make the numbers large enough to easily read while in the boat.

While you are measuring the sludge blanket depth, be sure to pull some core samples for Total Solids Analysis. This test will help you determine the tons of dry solids in your pond system. This number along with the volume of sludge will help contractors determine the cost to remove your sludge.



When you empty the contents of the core sampler into the bucket, the contents will run black with sludge and then clear. Add only the black or sludge portion of the core sampler into the bucket.

Figure 6. Preparing a Core Sample for Lab Analysis

Harvest about eight (8) or more composite samples randomly from the influent to the effluent across the treatment cell and put these in a bucket. One composite sample consists of three (3) or more core samples from an area added to the bucket. Mix the contents of the three or more samples in the bucket thoroughly to create one sample – a composite sample. Move to the next point and repeat eight (8) or more times. Sludge will change consistency from one end of the treatment cell to the other and from the top of the sludge blanket to the bottom and from one cell to the other.

Ask the lab how much sample they will require to perform a TS analysis. They will typically supply the sample bottles in the size they require.

Keep in mind that solids concentrations vary spatially along the length of a lagoon and from the top to the bottom of the sludge blanket as well. Sand, grit, and gravel will of course settle to the bottom of the sludge blanket, accumulate near the influent structure, and sludge will compact and concentrate over time making the very bottom of the blanket denser than the top of the blanket. Because of this you ***may*** be inclined to harvest discrete samples rather than making composite samples, and have eight (8) to twelve (12) samples analyzed separately and average the results of these individual samples. This will give you an idea of the variation of the sludge density and where the heaviest solids have accumulated.

Figure 7. Dave Axton with Water Resources Management, Pacific Missouri. Used with Permission

Be sure to wear eye protection when you are sludge judging and core sampling. Sludge is filled with pathogens and you do not want to have any of it splashing into your eyes.If the sludge blanket is extremely thick, over three feet (3') thick at each sample point, you may have to measure the water from the surface to the bottom of the pond (the water depth) and separately measure to locate the top of the sludge blanket. This is because it is difficult, even when using a two-inch (2") diameter sludge judge, to force three, four, or five feet of sludge up the sludge judge pipe. What will happen with thicker sludge is that when you slowly push the sludge judge through the sludge blanket, sludge will, at some point, resist going up further into the sludge judge tube. If it stops filling the sludge judge as you push the sludge judge through the sludge blanket, your sludge blanket depth measurement will be off by a foot or two. If you measure the water depth at each point first, and then use a separate sludge judge to locate the top of the sludge blanket, your accuracy will improve.

Once you get to shore and back to your desk, you can simply subtract the top of the sludge blanket depth from the total water depth to determine sludge blanket thickness. Rarely are the bottoms of ponds uniform in depth across the pond from influent to effluent and from side to side, so measure water depth **at each** sludge depth sampling point if you choose this method.

When in the boat, the navigator is typically recording the numbers you
call out to him, placing the numbers on your grid in the right location. Simply call out to him: “Water depth 10.5 feet top of sludge blanket located 4.25 feet down from the surface of the water”. It’s that simple.

I find using an Excel spreadsheet helps when I am back in the office to subtract the water depth from the top of sludge blanket number, run averages, and calculate volumes and mass. Excel also helps me create charts like the ones below.

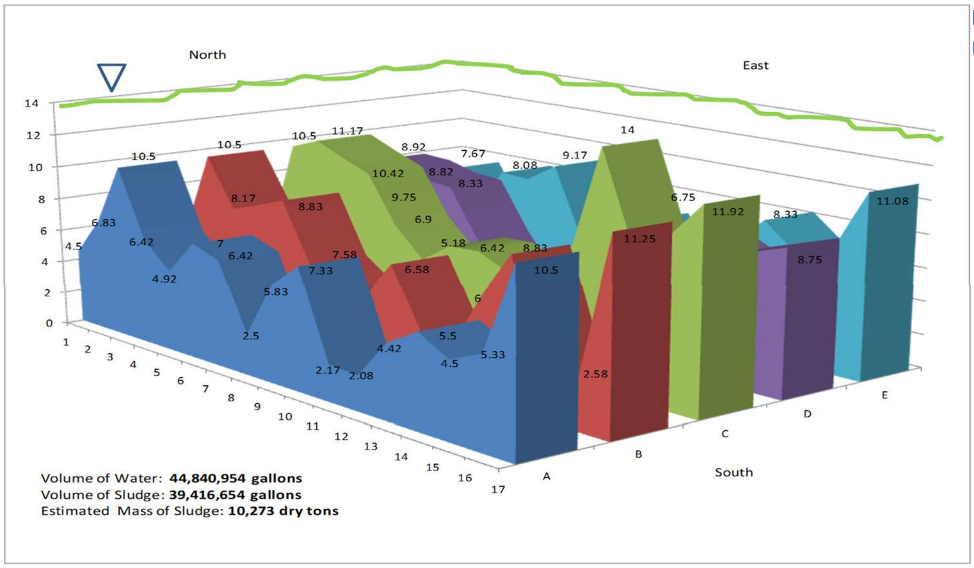


Figure 8. Sludge Blanket Profile Created Using Excel

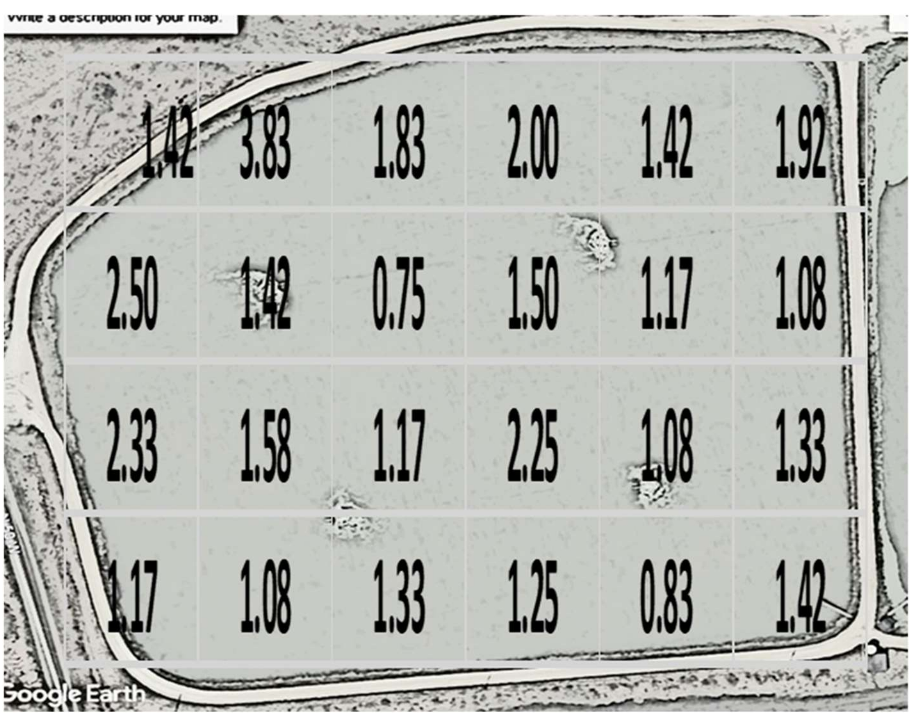
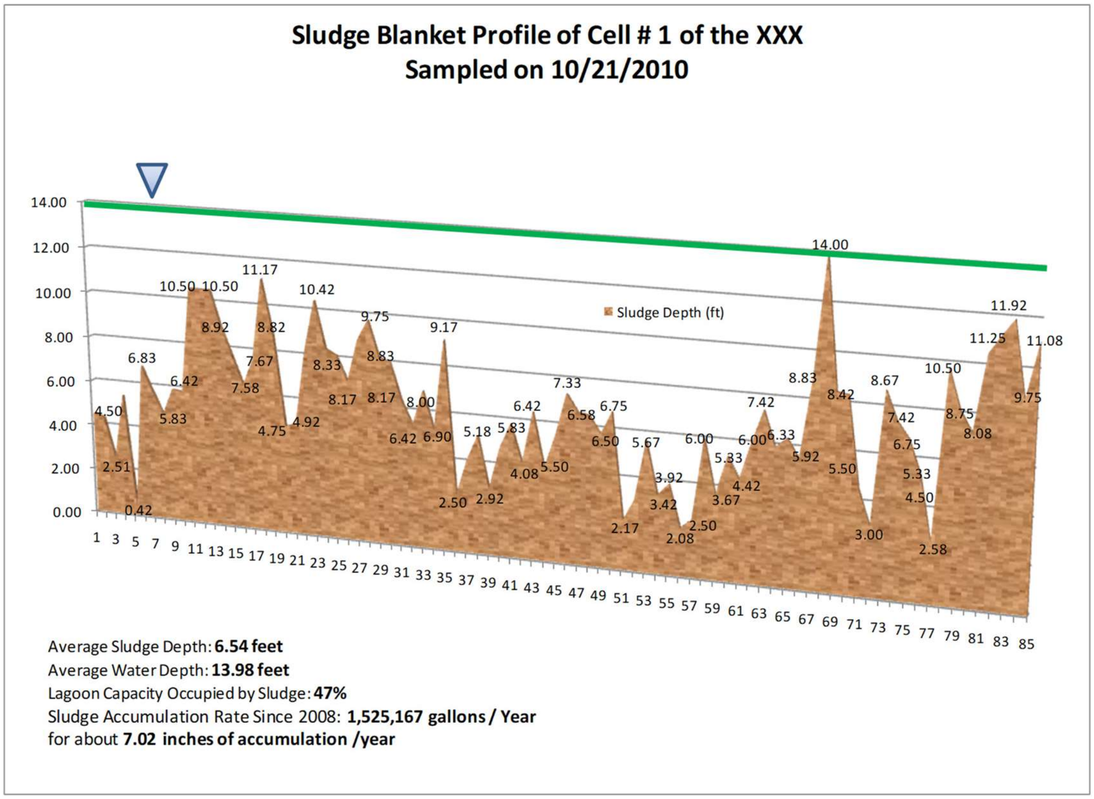


Figure 9. Sludge Blanket Thickness Locations Imposed on a Satellite Photo of Cell # 1



One note of caution when sludge judging and core sampling:

If clay and dirt have sloughed off into the bottom of the treatment cell, or if blow sand and dirt have accumulated at the bottom of the sludge blanket, this thicker, denser material may not be picked up in your core sampler for Total Solids analysis. If not picked up in your TS sample for the lab, this will cause error in your tonnage estimation. This is especially important when removing **ALL** the sludge to replace a liner. If the thicker heavier sludge is not accounted for, the contractor will find more solids to remove than calculated/estimated which can create financial problems when funding a sludge removal project. When performing calculations for sludge mass, assume at least 20% more than measured/tested for.

Steve Harris is the President and Owner of H&S Environmental in Mesa, AZ. Beginning in February 1993, Steve has worked with wastewater operators across the United States and in various parts of the world to identify and troubleshoot wastewater lagoon problems, optimize lagoon performance, and assist wastewater lagoon systems in removing sludge. Steve has written a lagoon troubleshooting manual; Wastewater Lagoon Troubleshooting and Optimization. To contact Steve Harris:

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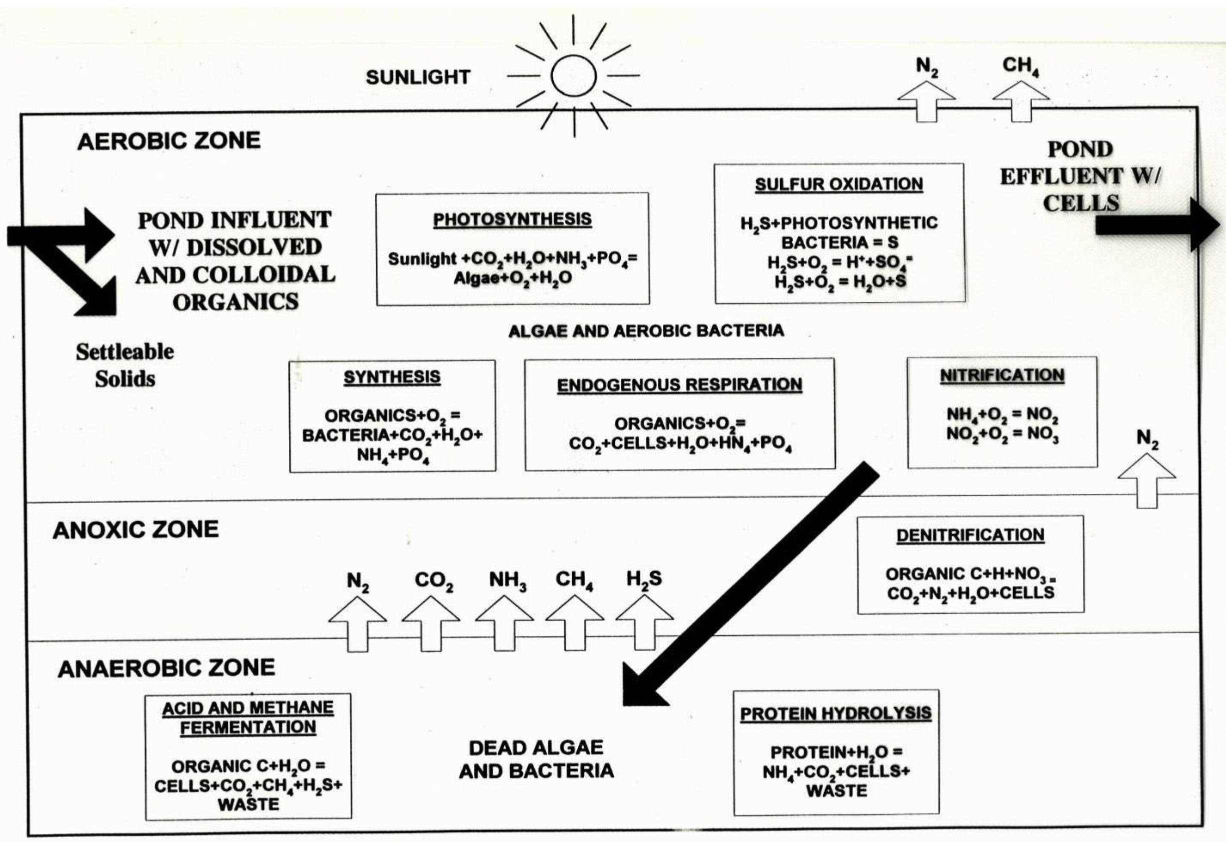
Multiple Level Draw off for Improved Effluent Quality

How Water Quality Changes with Changing Depths and How this can be Leveraged to Improve Discharge Quality

Because sunlight can penetrate to the depth of about two (2) to three (3) feet down into the water column of a treatment pond cell, most of the algae are concentrated in this area. This two (2) to three (3) foot band is called the photic zone and below this zone water has a tendency to be clearer, less inundated with algal suspended solids.

Along with lower suspended solids, other water quality parameters like pH, dissolved oxygen, BOD and pathogen counts also change. Microbial species diversity changes with changing depths and conditions. Because species diversity and community structures change, water chemistry changes. Because water chemistry changes water quality also changes and is distinct at each level down to the sludge water interface. Water quality changes both vertically and spatially across the treatment cell and between each cell.



BIOLOGICAL ACTIVITY IN A WASTEWATER POND SYSTEM
Figure II-2

<u>What if the operator could select the level of water he discharges from? What if the operator had a choice? Could this choice have an effect on the water quality he discharges? Yes. With multiple level draw off structures the operator does have a choice.</u>

TABLE IV

Changes in the activities of enzymes in different ponds

Enzyme	Depth (m)								
	0	0.31	0.61	0.91	1.22	1.52	1.83	2.13	1.44
Pond A									
Catalase	5.8 ± 1.3	5.8 ± 1.3	6.7 ± 1.3	10.2 ± 1.6	18.4 ± 2.6	—	—	—	—
Phosphatase	5.7 ± 0.6	5.7 ± 0.6	5.6 ± 0.2	5.8 ± 0.2	7.0 ± 0.4	—	—	—	—
Protease	5.9 ± 1.2	5.9 ± 1.2	7.0 ± 1.0	9.7 ± 1.2	18.7 ± 2.4	—	—	—	—
Amylase	10.7 ± 14.6	10.7 ± 16.6	29.3 ± 21.9	57.7 ± 10.2	80.8 ± 9.5	—	—	—	—
Pond B									
Catalase	8.5 ± 1.2	8.5 ± 1.2	10.3 ± 1.5	11.7 ± 1.3	14.3 ± 1.5	16.2 ± 1.1	23.1 ± 3.3	—	—
Phosphatase	4.7 ± 0.2	4.7 ± 0.2	5.5 ± 0.3	5.8 ± 0.2	5.8 ± 0.2	6.5 ± 0.3	7.6 ± 0.3	—	—
Protease	6.4 ± 0.2	6.4 ± 0.2	6.9 ± 0.3	9.6 ± 0.9	10.6 ± 1.4	14.6 ± 1.6	22.4 ± 2.1	—	—
Amylase	5.3 ± 7.3	10.7 ± 14.6	32.0 ± 15.2	56.4 ± 6.9	77.7 ± 5.1	77.7 ± 5.1	88.4 ± 12.2	—	—
Pond C									
Catalase	12.3 ± 2.8	12.3 ± 2.8	14.8 ± 2.8	18.4 ± 1.0	18.8 ± 1.4	21.7 ± 0.9	21.7 ± 0.8	27.3 ± 0.9	34.8 ± 2.5
Phosphatase	6.0 ± 0.4	6.0 ± 0.4	6.4 ± 0.2	6.7 ± 0.3	6.7 ± 0.2	7.1 ± 0.3	7.1 ± 0.3	7.6 ± 0.2	8.4 ± 0.3
Protease	9.9 ± 2.0	9.9 ± 2.0	11.7 ± 1.8	17.8 ± 1.6	17.8 ± 1.6	18.7 ± 1.7	18.7 ± 1.7	42.1 ± 3.8	47.2 ± 3.0
Amylase	5.3 ± 11.9	5.3 ± 11.9	16.0 ± 13.8	32.4 ± 28.3	59.1 ± 24.4	67.1 ± 13.4	89.2 ± 8.4	112.0 ± 11.9	133.3 ± 37.7

TABLE II

Changes in physical, chemical and biological parameters of wastewater in pond A, B, and C (average values ± SD)

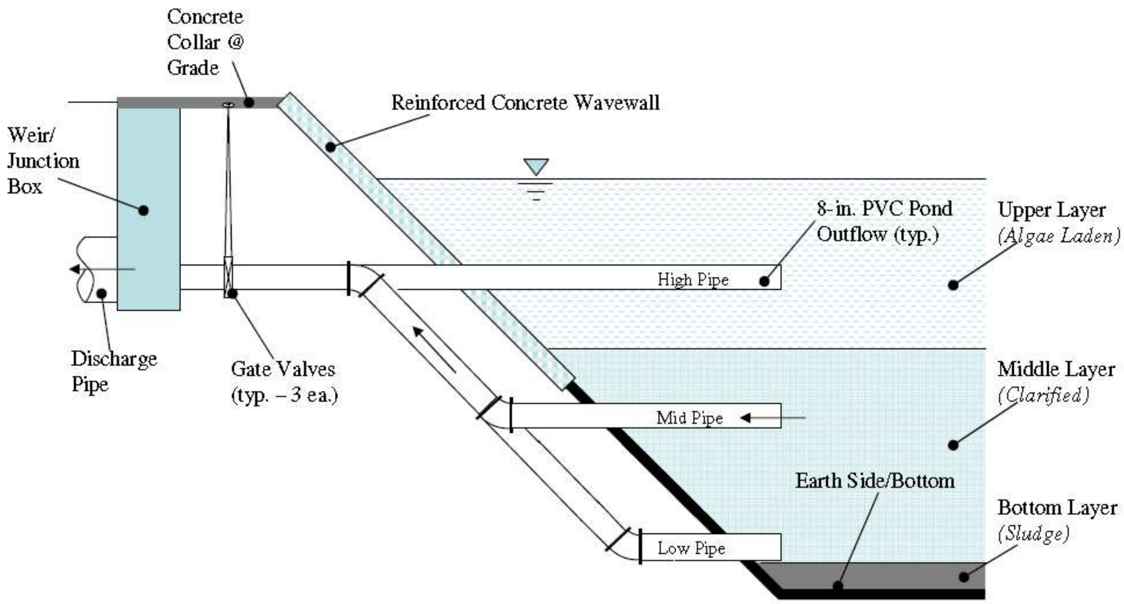
Depth (m)	DO mg L^{-1}	pH	Temp. °C	NH_3N mg L^{-1}	PO_4 mg L^{-1}	BOD mg L^{-1}	Algae $\times 10^3$ mL^{-1}	Bacteria $\times 10^4$ mL^{-1}
Pond A (1.22 m)								
0	14.3 ± 0.7	9.6 ± 0.3	28.2 ± 0.8	1.4 ± 0.4	2.0 ± 0.2	58.2 ± 8.2	238.8 ± 9.4	9.4 ± 1.1
0.31	14.3 ± 0.7	9.5 ± 0.5	28.2 ± 0.8	1.4 ± 0.4	2.0 ± 0.2	58.2 ± 8.2	287.2 ± 9.9	9.8 ± 1.3
0.61	11.4 ± 0.8	9.0 ± 0.4	27.6 ± 0.8	2.0 ± 0.3	2.8 ± 0.5	65.9 ± 7.5	232.6 ± 14.7	13.4 ± 2.1
0.91	9.2 ± 0.3	8.2 ± 0.1	26.8 ± 0.7	3.8 ± 0.9	3.8 ± 0.3	85.0 ± 9.8	182.0 ± 15.0	23.2 ± 1.9
1.22	7.2 ± 0.2	7.2 ± 0.2	26.4 ± 0.6	6.1 ± 0.6	5.2 ± 0.4	129.4 ± 15.8	124.2 ± 9.0	64.8 ± 6.3
Pond B (1.83 m)								
0	14.0 ± 1.2	9.4 ± 0.2	28.2 ± 0.8	1.7 ± 0.4	2.3 ± 0.3	68.6 ± 2.1	263.4 ± 13.2	10.0 ± 1.0
0.31	13.9 ± 1.2	9.4 ± 0.2	28.2 ± 0.8	1.7 ± 0.4	2.3 ± 0.3	68.8 ± 2.1	262.0 ± 12.6	11.4 ± 1.9
0.61	12.9 ± 0.9	9.1 ± 0.2	27.7 ± 0.6	2.3 ± 0.4	3.0 ± 0.5	71.9 ± 2.6	245.4 ± 12.2	13.2 ± 1.3
0.91	12.0 ± 0.5	9.0 ± 0.1	27.7 ± 0.8	2.5 ± 1.2	3.4 ± 0.1	85.3 ± 4.8	228.0 ± 12.7	21.4 ± 3.1
1.22	10.4 ± 0.2	8.3 ± 0.1	26.7 ± 0.7	3.6 ± 0.5	4.2 ± 0.2	96.5 ± 10.3	214.0 ± 47.3	27.2 ± 2.4
1.52	8.1 ± 0.1	8.5 ± 0.2	25.6 ± 0.5	4.1 ± 0.4	4.6 ± 0.5	106.0 ± 13.7	137.6 ± 14.3	42.2 ± 3.9
1.83	7.1 ± 0.2	7.3 ± 0.2	25.6 + 0.5	5.7 ± 0.5	5.9 ± 0.2	130.8 ± 4.8	119.6 ± 12.4	66.4 ± 2.7
Pond C (2.44 m)								
0	12.5 ± 1.2	9.2 ± 0.2	28.2 ± 0.9	2.8 ± 0.5	2.8 ± 0.3	72.2 ± 4.9	244.7 ± 9.7	10.6 ± 2.7
0.31	12.0 ± 0.9	9.1 ± 0.2	28.2 ± 0.8	2.8 ± 0.4	2.8 ± 0.3	72.2 ± 7.1	245.0 ± 4.6	10.6 ± 2.7
0.61	11.5 ± 0.2	9.1 ± 0.2	27.3 ± 0.8	3.3 ± 0.4	3.3 ± 0.3	85.6 ± 7.1	236.8 ± 4.6	13.1 ± 2.7
0.91	10.0 ± 0.5	8.7 ± 0.1	27.4 ± 0.8	3.3 ± 0.4	3.3 ± 0.4	87.2 ± 7.2	234.0 ± 7.5	16.4 ± 2.6
1.22	9.2 ± 0.5	8.5 ± 0.1	26.7 ± 0.7	4.1 ± 0.5	3.7 ± 0.2	100.4 ± 3.3	197.2 ± 5.9	16.6 ± 2.4
1.52	8.5 ± 0.2	8.2 ± 0.1	26.6 ± 0.5	4.6 ± 0.6	4.7 ± 0.3	103.0 ± 7.8	182.4 ± 8.3	24.6 ± 2.2
1.83	7.5 ± 0.3	8.3 ± 0.1	26.4 ± 0.6	5.3 ± 0.4	6.3 ± 1.0	128.4 ± 6.7	150.0 ± 8.7	25.6 ± 3.0
2.13	7.2 ± 0.2	7.2 ± 0.1	25.9 ± 0.4	6.4 ± 0.4	7.0 ± 0.5	130.0 ± 4.5	126.8 ± 9.4	36.0 ± 5.1
2.44	7.0 ± 0.2	7.0 ± 0.6	25.8 ± 0.4	8.0 ± 0.6	7.4 ± 0.3	144.0 ± 11.8	90.6 ± 5.0	75.4 ± 5.7

TABLE III

Percent removal of ammonia nitrogen, phos bacteria, and BOD

Depth (m)	NH_3N	PO_4	Bacteria
Pond A			
0	92.5	76.3	99.8
0.31	92.5	76.5	99.8
0.61	89.3	67.9	99.7
0.91	79.9	55.9	99.5
1.22	68.1	40.3	98.6
Pond B			
0	90.8	73.2	99.8
0.31	90.8	73.2	99.8
0.61	87.9	65.4	99.7
0.91	87.5	60.4	99.5
1.22	80.9	50.8	99.4
1.52	78.6	47.1	99.1
1.83	69.9	30.9	98.6
Pond C			
0	85.2	67.2	99.8
0.31	85.2	67.2	99.8
0.61	82.4	61.9	99.7
0.91	82.4	61.5	99.6
1.22	78.5	57.5	99.6
1.52	75.6	45.2	99.5
1.83	72.2	28.3	99.5
2.13	66.1	19.4	99.2
2.44	58.0	13.7	75.4

Countless tests by operators in the field, and researchers the world over have confirmed that if deep enough, water quality in a pond treatment cell will change with changing depth. There is a "sweet spot" where water quality is just right to provide effluent discharge that meets permit limits. It is the operator's job in plants with variable level draw off structures to find and manage that sweet spot to insure discharge water that meets water quality permit limits.



Multi-Level Outflow Diagram
Not to Scale

Smith Engineering Company FIGURE 4

With an effluent discharge structures like the ones shown above and below the operator can select the depth of the water column he discharges from. He can blend the water…take a portion from the top, a portion from the middle, or perhaps even a portion from the bottom to meet his particular need. The operator can even select the “sweet spot” somewhere in the middle where TSS is lowest, pH is just right, ammonia is down. and the D.O. is at concentrations that are suitable to meet permit limits.

An operator lowers his sludge judge and pH/DO meter down and sees where the water quality is best. There are even TSS meters available from HACH that can be lowered down to measure the TSS rather than eyeball the turbidity through the clear plastic tube of the sludge judge.

Configured like the discharge structure to the left, the operator has a choice. He can choose the water quality he releases. Be aware that a discharge structure like this one requires at least an eight (8) foot depth to work with.

Shallow ponds like the ones used by TESi are typically well mixed through the entire water column and have algae from the surface of the pond all the way to the bottom. TESi ponds would probably not benefit from a variable depth draw off structure like the one pictured to the left. Even though TESi ponds are shallow, TESi should try to avoid drawing water from the surface.

For deeper ponds multiple level draw off structures make an effective upgrade to improving pond discharge.

Top, Middle, and or Bottom

Steve
Harris
President
H&S Environmental, LLC

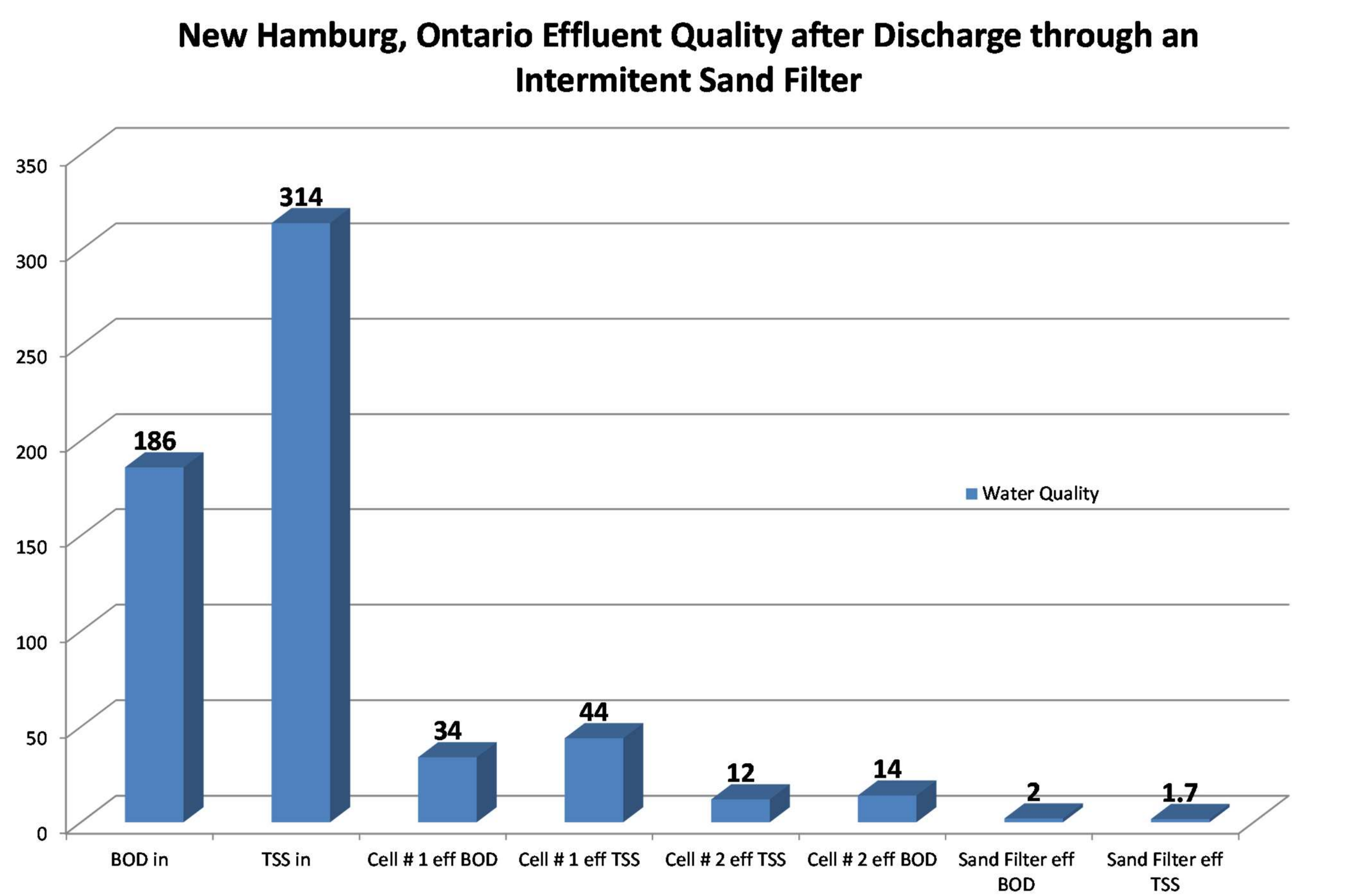
- Sludge Removal
- Performance Evaluations
- Troubleshooting & Optimization
- Hydraulics Optimization

H&S Environmental, LLC. 2122 East Leland Circle Mesa, AZ 85213 1 (602) 810-7420

Sand Filtration for Tertiary Treatment of Lagoon Effluent

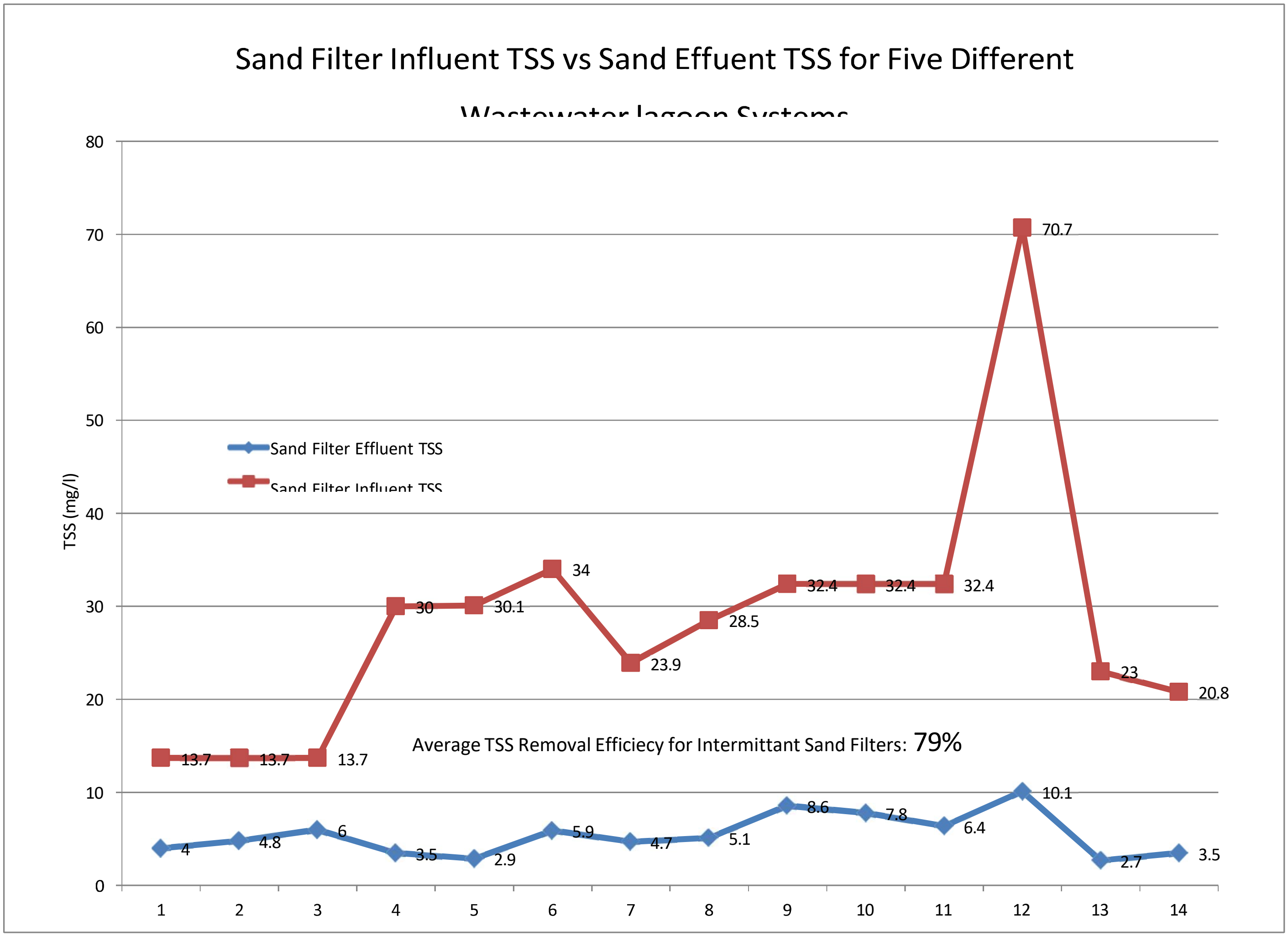
Sand filters have been used for decades across this country to effectively polish wastewater lagoon effluents down to the single digit level at a relatively low cost. In fact effluents from intermittent sand filters rival the water quality of packaged activated sludge systems. Intermittent sand filters apply pond effluent to a sand filter media bed on an intermittent basis and because these filters remove pollutants physically and biologically, they are also known to effectively remove ammonia as well as BOD and TSS.

Below are some examples of sand filters used by various communities.

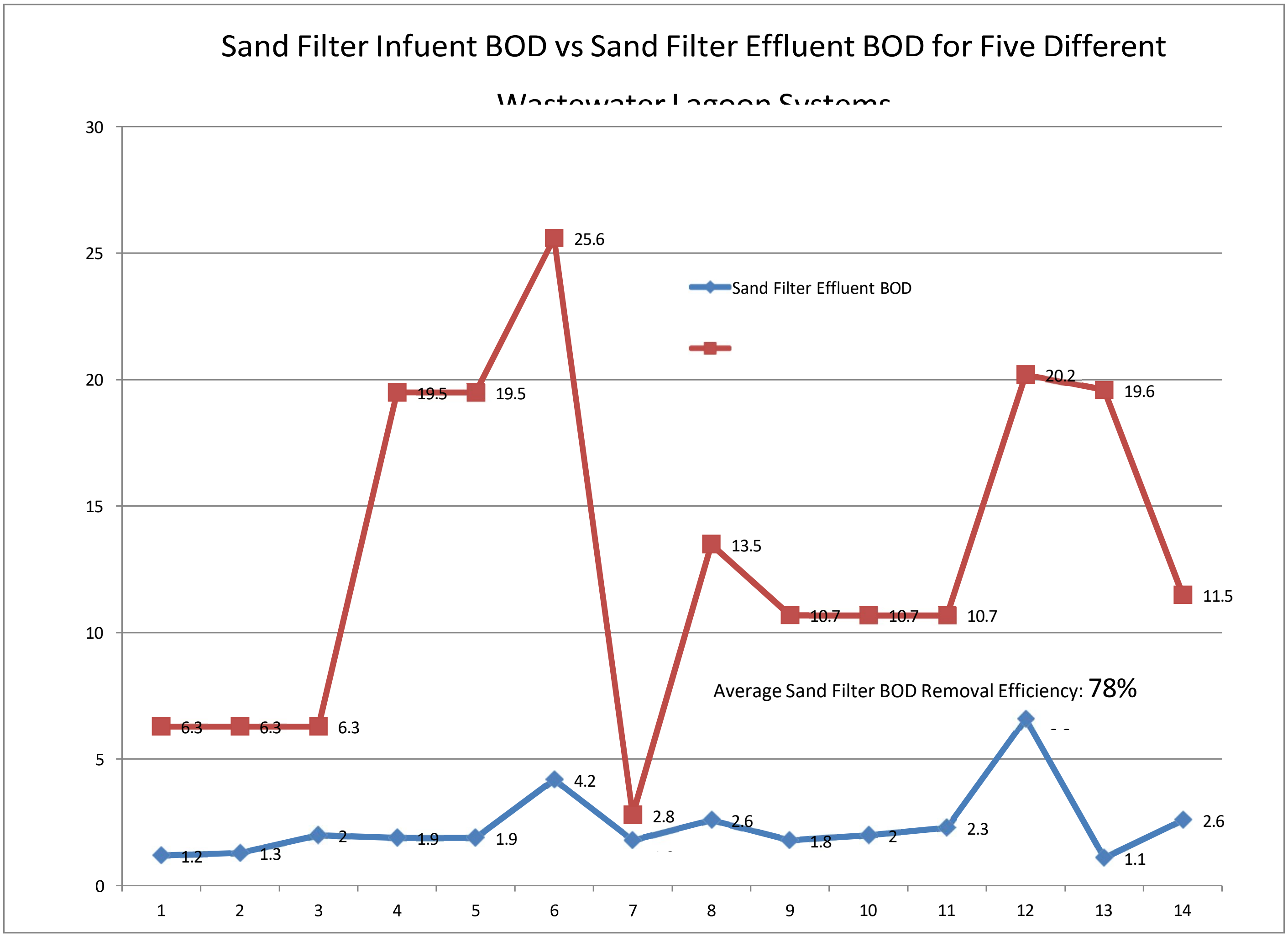


Adapted from: Performance of Aerated Pond-Intermittent Sand Filter, New Hamburg, Ontario Plant (Melcer et al., 1995) from Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers (EPA/600/R-11/088) August 2011

Below is a chart representing five (5) different communities' experiences all using intermittent sand filters.



You will notice the average TSS removal efficiency for these five (5) different sand filters is seventy-nine (79) percent and the BOD removal efficiency is seventy-eight (78) percent. The addition of an intermittent sand filter (or DynaSand) to any one of the 10/15 TESI lagoons will more than any other upgrade (aside from desludging) get these plants in compliance. Most communities using sand filters report long term and sustained single digit TSS and BOD compliance.



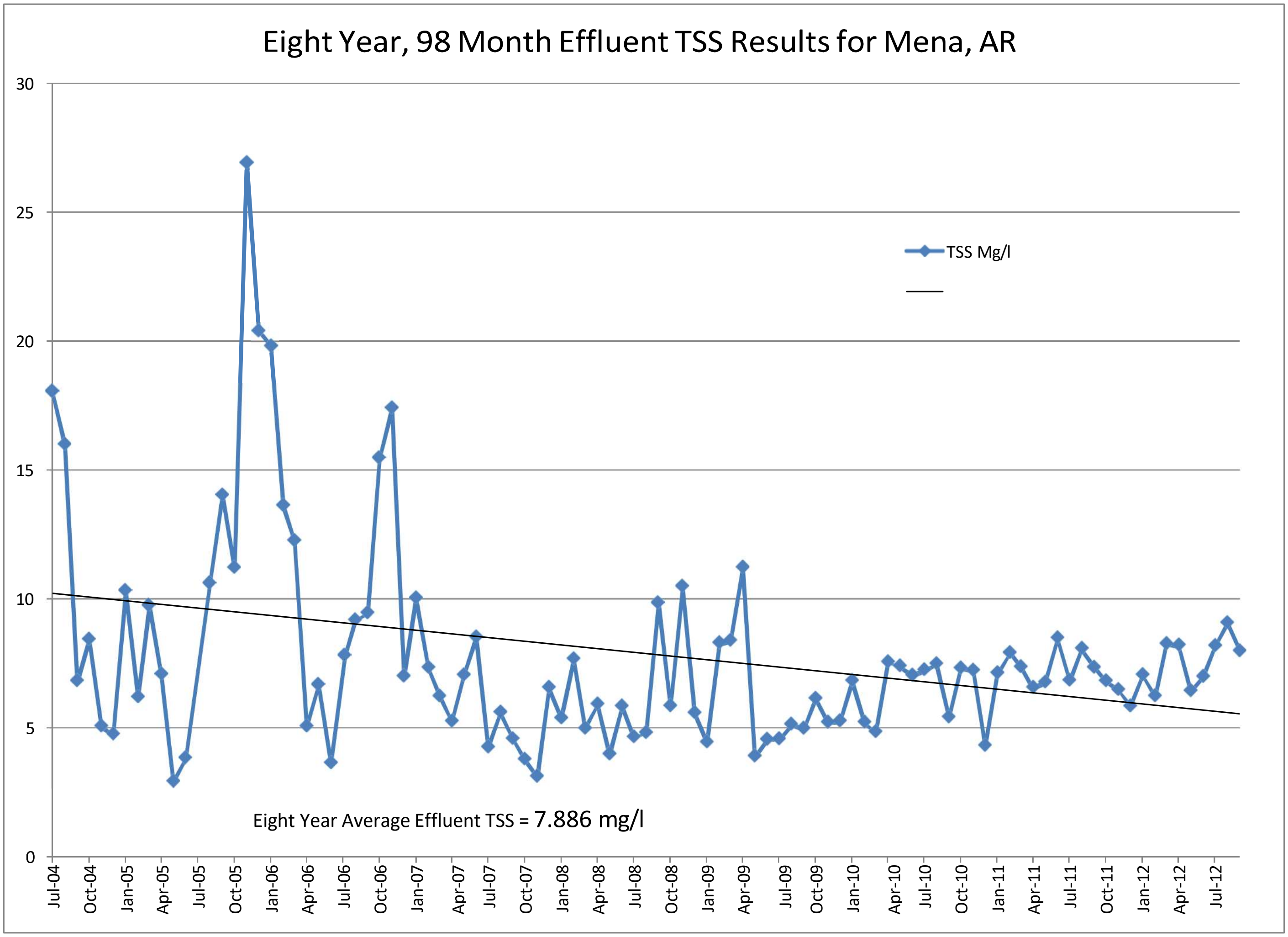
Sand filtration improvements are not only restricted to effluent TSS control but BOD as well. In the chart above these five communities reported an average BOD reduction of 78%. Most if not all of TESIs lagoons would benefit from the addition of an intermittent sand filter. Sand filters have proven effective across the county.

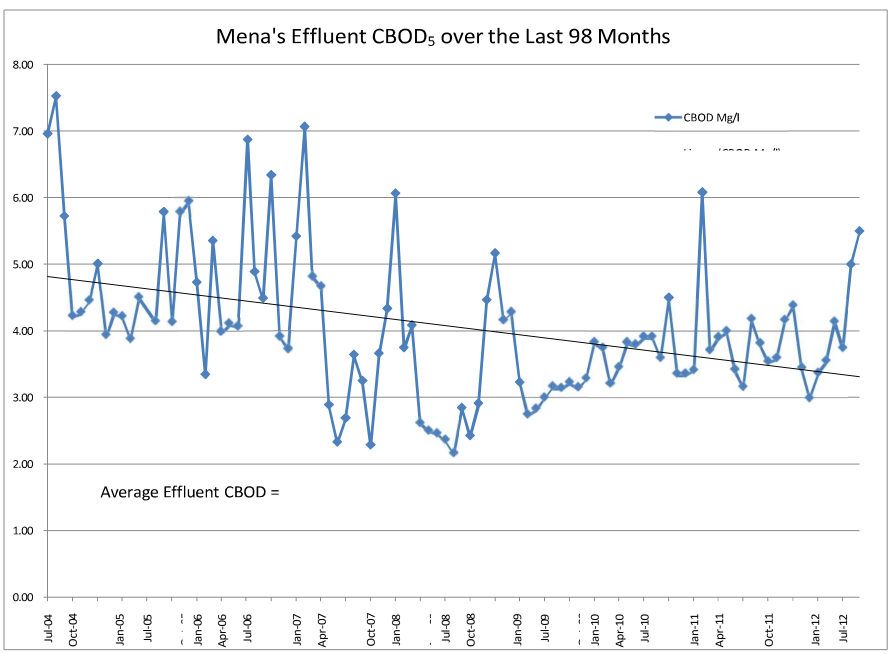
Mena Arkansas has been successfully using a DynaSand sand filtration system for years. Mena routinely produces single digit BOD and TSS throughout the year as can be seen in the charts below. Mena's DynaSand® Filter is a continuous backwash upflow, deep bed, granular media filter that uses alum as a coagulant.

Because of attachment sites in the sand / media bed, nitrifying bacteria can exist in sufficient numbers to reduce ammonia down to compliance levels.

Maintenance is directly related to the TSS applied to the surface of the filter. Filters with low hydraulic loading rates tend to operate for extended periods. With such extended operating periods, maintenance consists of routine inspection of the filter, removing weeds, and an occasional cleaning by removing the top 5 - 8 cm of sand after allowing the filter to dry out. Early control of weeds is the key to good maintenance. The use of chemicals is not advised. Some sort of sun/shade cloth over the filters is advised. This is the same material available at hardware stores to prevent weed growth.

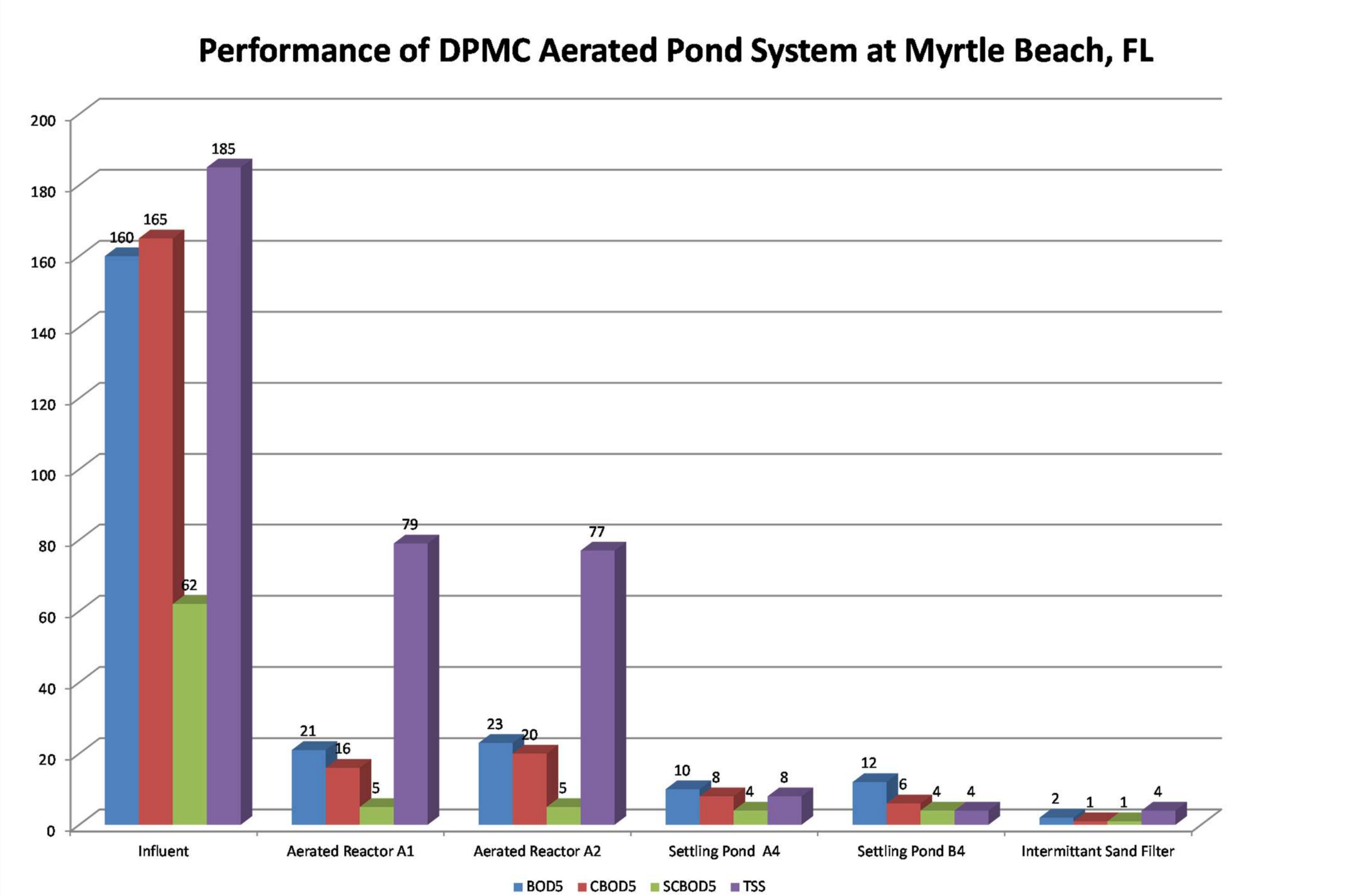
DynaSand sand filters like the ones used at Mena Arkansas require no weeding, have no moving parts and are self-cleaning. The filters at Mena also remove phosphorous and copper while reducing BOD, TSS,





and ammonia.

For over 12 years the Myrtle Beach plant has not had a discharge TSS over 15 mg/l from their sand filters as can be seen in the chart below.



Adapted from: Performance of Aerated Pond-Intermittent Sand Filter, New Hamburg, Ontario Plant (Melcer et al., 1995)
from Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers (EPA/600/R-11/088) August 2011

Sand filters of all types have proven themselves effective at polishing wastewater pond system effluents to very low levels of BOD and TSS. Serious consideration should be given by TESI to polishing their lagoon effluents using some sort of sand filtration. This alternative is cheaper than replacing the pond systems with packaged treatment plants.

Steve Harris
President
H&S Environmental, LLC

Sludge Blanket Mixing in Wastewater Stabilization Pond Systems

Steve Harris, President and Owner of H & S Environmental, LLC

A facultative or partially mixed lagoon treatment cell is like having three wastewater reactors stacked one on top of the other. These reactors influence each other by generating waste products unique to the microbial community that lives within each of them. In facultative or partially mixed treatment cells, there is an aerobic reactor at the top, an anoxic selector in the middle, and an anaerobic digester at the bottom depending on treatment cell depth, oxygen currents, loading, mixing, and other factors.

The focus of this brief discussion is on the value of mixing the sludge blanket at the bottom part of the treatment cell; the anaerobic / anoxic portion.

Mass Removal by Digestion

In its simplist terms, anaerobic digestion is the breakdown of sludge into methane, carbon dioxide, and water by anaerobic microorganisms. Aerobic digestion is the breakdown of sludge into carbon dioxide and water by aerobic microbes. Both of these are multi-step processes used to reduce the volume of wastewater sludge. A digester (or sludge blanket in a pond system) is composed of countless trillions of microbes consuming organic and inorganic materials and then generating waste products that MUST get to other microbes to complete the stabilization process. If these waste products cannot get to the other microbes, toxicity builds and the process stops.

Because acids are formed before methane is produced in anaerobic systems, these acids MUST get to the methanogens responsible for methane production for mass to be reduced. Mixing is one of the key elements in the process of anaerobic digestion. In aerobic digestion, nitric acid, ammonia, and nitrates are produced that MUST be converted by microbes to safer less toxic by-products.

The importance of good mixing in anaerobic and aerobic digesters cannot be overstated. Mixing provides:

- The uniform availability of food for microbes
- The dispersion of waste products to avoid self-limitation (toxicity)
- pH balance due to acid formation
- A closely maintained association between living/active biomass and incoming food
- Enhanced biological reaction rates
- Improved VSS reduction efficiency
- Increased gas production
- Decreased sludge blanket mass

When sludge solids are converted into a gas and water (CO_2, CH_4, H_2O) there is a “mass transfer”. Mass that was once solid, is now mass in the form of gas and liquid (water).

Looking at the chemical composition of wastewater pond sludge (dead and living bacteria, algae, raw organic matter, duckweed, plant material and other organic material) we see that a large portion of sludge can be converted into “something else”:

The building blocks of sludge

Table 3.1 Elemental composition of microbial cells.

Elemental	Variations in composition of microbial cells, dry weight %
Carbon	45 – 55
Oxygen	16 – 22
Nitrogen	12 – 16
Hydrogen	7 – 10
~~Phosphorus~~	~~2 – 5~~
Sulfur	0.8 – 1.5
Potassium	0.8 – 1.5
Sodium	0.5 – 2.0
Calcium	0.4 – 0.7
Magnesium	0.4 – 0.7
Chlorine	0.4 – 0.7
Iron	0.1 – 0.4
All others*	0.2 – 0.5

* Includes trace elements.

These elements can form gasses

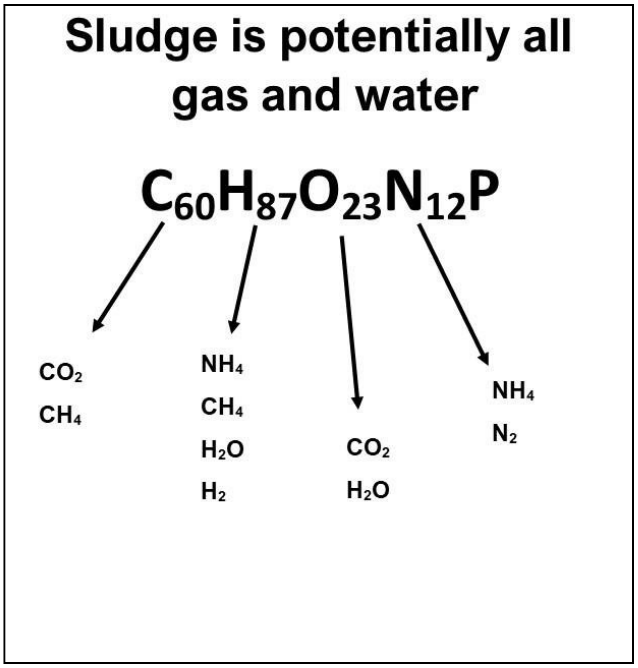
85% of dead bacteria and algae mass can be converted to gas

Sludge is mostly composed of Carbon, Oxygen, Nitrogen, and Hydrogen, and under the right conditions, these elements can be converted into gas.

	Organic Fraction (%)					
Emprical Formula	**Carbon**	**Oxygen**	**Hydrogen**	**Nitrogen**	**Phosphorous**	**References**
	52.4	26.8	6.3	12.2	2.3	McCarty (1970)
Activated Sludge	53	30.5	6.4	8.9	1.2	Sawyer (1956)
$C_{60}H_{87}O_{23}N_{12}P$	44.9	35.4	6.9	10.7	2.1	Speece and McCarty (1964)
$C_{118}H_{170}O_{51}N_{17}P$	52.4	29.7	7.4	9.2	1.3	Strumm and Tenney (1964)
Anaerobic Sludge						
$C_{54}H_{99}O_{32}N_{11}P$						
Algae						
$C_{106}H_{181}O_{45}N_{16}P$						
Gasses Produced	CO_2	CO_2	NH_4	NH_4		
from sludge blankets	CH_4	H_20	CH_4	N_2		
			H_20			
			H_20			
Adapted from Wastewater Biology: The Life Processes, 1994						

Image Adapted from: WEF, (1994) Wastewater Biology: The Life Processes, A Special Publication. Prepared by the Task Force on Wastewater Biology: The Life Process. Water Environment, Federation, Alexandria, VA ISBN 1-881369-93-5

Because sludge is potentially gas, water, and nutrients, mixing becomes a key element in sludge's conversion to other products. This explains the emphasis that is placed on mixing in aerobic and anaerobic digesters.



Compared to digesters, sludge at the bottom of a lagoon does not mix well.

When sludge judged, large amounts of gas are typically released from the sludge blanket that has been disturbed. In theory, this gas is composed of 70% methane and 30% carbon dioxide. Because lagoon sludge blankets do not mix well, the waste by-products from one microbe are not efficiently delivered to the next microbe who can use them, consume them, and convert them…Nature's Self-Purification process is diminished. This is similar in principle to why a maximum of 12% by volume of alcohol is all that can be produced by a standard batch of yeast and sugar…the yeast self-limits…dies in its own waste products. Toxicity accumulation in a sludge blanket limits mass reduction in a similar manner.

Mixing can also reduce the impact of toxic material (i.e. ammonia) accumulation by diluting it in the pond volume below levels that would inhibit methane formation. Toxicity is also reduced by delivering toxic materials to microbes that can consume them, H_2S (Hydrogen Sulfide) as an example. Essentially, mixing adds capacity to a treatment cell. It uses the existing capacity more efficiently.

In the 1983 ASCE Nationwide Survey of Anaerobic Digesters, active mixing was found to be the most significant factor in reducing volatile solids. In this survey, 13 WWTPs reported "inadequate" mixing but still reported >50% VSS Reduction.

In the 2005/06 Carollo Survey on Digesters, VSS reduction varied between 44% - 68% whereas the most common range of reduction was between 50% - 55%.

"The mixing characteristics of a reactor, and the manner in which wastewater is introduced into the reactor, exert a considerable influence on the efficiency of treatment. Many important parameters are influenced by these hydraulic flow characteristics including BOD removal, settling characteristics…and pathogen removal in waste stabilization ponds"

-Biological Wastewater Treatment Systems: Theory and Operation, N.J. Horan

One of the keys to effective anaerobic or aerobic digestion is mixing. On the average, suspended sediments (mixed sediments) consume as much as 4.96 mg O_2/day which is 900 times more than unmixed sediments. As sediments are mixed, respiration rates can increase by 300 times.

In anaerobic systems, the acids formed by acidogenic bacteria and other essential nutrients must find their way to the methane producing bacteria. The more efficiently this happens, the faster and more complete the solids are stabilized…mass reduced. In aerobic systems, mixing is equally important to improve efficiency. This is why there is a mixing phase in the air-off cycle of aerobic digester operation. During the air-off phase, mixing delivers the nitrates to the denitrifying biomass and the nitrates are consumed.

In short, the two basic reasons for mixing aerobic and anaerobic biomass are to:

1. Maintain the viability of the biomass by:
    a. improving the consistency of food delivery to the biomass
    b. by-product toxicity removal
2. Minimize the mass and volume of lagoon sludge blankets

Anaerobic and aerobic digestion is highly dependent upon effective sludge mixing. Without assistance, lagoon sludge blankets mix poorly, and solids accumulate. With mixing, lagoon sludge blankets are reduced.

WARNING!! BE CAREFUL NOT TO OVER MIX!! Mix a small portion of the lagoon's sludge blanket at any given time as nutrients will be released, dissolved oxygen will plummet, and the potential for permit violations increase.

Steve Harris is the President and Owner of H&S Environmental in Mesa, AZ. Since his beginning in February 1993, Steve has worked with wastewater operators across the United States and in various parts of the world to identify and troubleshoot wastewater lagoon problems, optimize lagoon performance, and assist wastewater lagoon systems in removing sludge. Steve was the featured wastewater presenter at MRWA's 2018 Bootheel Expo and 2018 Fall Operations & Maintenance Symposium.

To contact Steve Harris by email:
lagoonops@gmail.com.

Appendix C: Mechanical Plant Site Visit Reports

Fergus Falls MN

The following participated in our discussion:

Matt Lemke (Fergus Falls)

Stephan Nelson (Fergus Falls)

Randy Thorson (MPCA)

Grant Weaver (Grant Tech)

Design flow: 2.8 MGD

Typical actual flow: 1.5 MGD

Influent BOD: 150-170 mg/L

Influent Phosphorus (in-house testing): 3-5 mg/L

Effluent total-Phosphorus: 0.3 mg/L

Effluent Ammonia: 1-1.5 mg/L

Effluent total-Nitrogen: 12-16 mg/L

Effluent Nitrite+Nitrate: approximately 10 mg/L

Total-Phosphorus effluent limit: 1.0 mg/L

Ammonia effluent limit: I failed to write this down

Total-Nitrogen limit: no limit currently but potentially 10 mg/L in future permits

Treatment consists of two primary clarifiers followed by two parallel three-pass aeration basins.

The first pass of each aeration basin receives primary effluent and return sludge; this zone is mixed but not aerated.

The second two passes are aerated.

Prior to disinfection, flow passes through two secondary clarifiers.

Phosphorus removal

Fergus Falls effectively, consistently removes phosphorus to less than 0.5 mg/L.

The pre-anoxic zone may be assisting with biological phosphorus removal, but I suspect the majority of the phosphorus removal is chemical.

Here's why I believe this.

Stormwater and decant water from the city's water treatment plant sludge lagoons is sent to the wastewater treatment plant for treatment.

This water likely contains chemicals (alum) which assist in inorganic phosphorus removal.

Plus.

Alum is added to the clarifier inlet during winter months to assist with settling and minimize the freezing of floating debris in the secondary clarifiers.

Alum is also added for several weeks during spring and fall when the sludge holding tank is decanted.

Alum interacts with soluble phosphorus to create a TSS containing phosphorus that is removed with waste activated sludge.

The current operational strategy provides effective phosphorus removal; unless and until Fergus Falls wishes to eliminate alum addition, there isn't much room for improvement.

My recommendation, therefore, is to keep doing what you are doing!

As an intellectual exercise, staff are encouraged to monitor the orthophosphate concentration through the plant to identify where phosphorus is removed.

If an appreciable amount of biological phosphorus removal is occurring, the PAOs (phosphate accumulating organisms) that live in and with the mixed liquor need to (a) feed on volatile fatty acids in septic conditions and (b) multiply in aerobic conditions.

As PAOs are energized, they temporarily release orthophosphate into solution.

All of which means …

A good way of sleuthing out how much biological phosphorus removal is occurring is to measure the orthophosphate concentration of the primary effluent / return sludge blend and compare that concentration to the orthophosphate concentration in the mixed liquor leaving the pre-anoxic zone.

A "just right" ratio is three times as much orthophosphate leaving the anoxic zone as entering it; yes, <u>more</u> phosphorus in solution.

I suspect you'll find that there is little change, that the orthophosphate concentrations entering and exiting the pre-anoxic zone are nearly the same.

Which, if true, means there is little biological phosphorus removal happening.

Nitrogen removal

I suspect the pre-anoxic zones are helping with nitrogen removal by removing nitrate from the return sludge.

(Nitrate, you recall, is created as ammonia is removed.)

This suspicion can be confirmed (or refuted) by measuring the nitrate concentration in the primary effluent / return sludge blend and comparing the concentration to that of the mixed liquor leaving the pre-anoxic zone.

If my theory is correct, you'll find a higher concentration of nitrate coming into the anoxic zone than leaving.

After gaining an understanding of what, if anything, the pre-anoxic zone is doing for nitrate removal, two practical opportunities for enhancing nitrate removal sufficiently to lower effluent total-nitrogen to below the 10 mg/L target that may be forthcoming are worth consideration.

1. Boost nitrate removal performance in the pre-anoxic zone.

2. Cycle aeration equipment on and off to provide alternating high dissolved oxygen (DO) conditions for ammonia-nitrogen conversion to nitrate-nitrogen and low DO conditions for nitrate-nitrogen conversion to nitrogen gas.

Both are discussed below.

Optimizing pre-anoxic nitrate removal

To boost nitrate removal in the pre-anoxic zone, I recommend taking one of two primary clarifiers off-line so that the bacteria that remove nitrate have more food.

That is, more BOD (biochemical oxygen demand) flowing into the anoxic zone.

And.

Shut off mixers in the anoxic zones for extended periods of time so that sludge settles and creates a greater oxygen demand in the sludge blanket thereby enhancing anoxic conditions.

My suggestion: begin by operating with two of four mixers off for one day (#1 & #3) and the other two mixers (#2 & #4) off the following day.

Watch for drops in mixed liquor concentration … if this occurs, then more mixing is required.

And.

Don't allow any one area of the tank go without mixing for at least 15 minutes every few days as the settled sludge may begin to decay and release too many nutrients (ammonia and phosphorus) into solution.

The efforts described above should improve nitrate removal but likely not enough to bring effluent total-nitrogen concentration consistently below 10 mg/L.

The second step, optimizing nitrate removal in aeration basins, will likely prove necessary to fully optimize nitrogen removal.

Optimizing nitrate removal in aeration basins

Keep the second and third passes in each of the two trains with enough DO for long enough time to remove most of the ammonia while cycling air off long enough to remove more of the nitrate-nitrogen that is produced as ammonia-nitrate is removed.

Start conservatively by ensuring that there is always enough air-on time of high enough DO to remove ammonia sufficiently to maintain permit compliance.

Turn the air off for one hour in the morning and one hour in the afternoon.

This shouldn't make any difference in effluent quality, you shouldn't see any difference in treatment: nothing gets worse, nothing gets better.

After a week, extend the air-off cycles to two hours duration.

With two consecutive hours of off time, the nitrate-nitrogen concentration should begin to drop.

Daily measure effluent ammonia to ensure that the air isn't off for too long.

Daily measure effluent nitrate to monitor how effective the air-off cycles are working.

Continue making adjustments by (a) shortening the air-on cycles and/or (b) extending the air-off cycles.

Check in with me periodically by phone (860.777.5256) or email as I'm forever available to discuss air cycle settings with you.

MPCA

I'm glad Randy Thorson was present for the visit as I don't want you to cross wires with MPCA.

By copy of this email, I'm asking Randy to have someone from MPCA advise you on how they'd like you to proceed with my recommendations (if at all) as there may be some paperwork involved.

Grand Forks ND

The following participated in our discussion:

Tod Matelski (Grand Forks)

Grant Weaver (Grant Tech)

Design flow: 15 MGD

Actual flow: 7.5-8.5 MGD average, 10-12 MGD wet weather

Effluent total-Phosphorus: 6.0 mg/L

Effluent Ammonia: 0.5-2.0 mg/L

Effluent total-Nitrogen: 22-25 mg/L

Effluent Nitrite+Nitrate: approximately 20 mg/L

Currently there are no effluent limits for total-Phosphorus or total-Nitrogen

I failed to write down what the ammonia limits are

Effluent pH must be maintained at 7.0 or higher

Treatment consists of four aeration reactors (three of which are currently in use as there is more capacity than presently needed).

Each of the aeration reactors is 40-feet deep with a 3.5-million-gallon capacity.

Clarification is performed using a series of micro-bubble flotation (MBF) clarifiers preceded by flocculation chambers.

Followed by disinfection.

Waste sludge is discharged to the lagoon.

The lagoon and the mechanical plant discharge separately to the Red River.

The aeration reactors are operated in series.

Existing piping installation doesn't allow for operating basins in parallel.

Exiting piping installation requires that a minimum of two basins in service at any one time.

As currently configured …

Screened influent is pumped into Aeration Basin #1.

Air in #1 is cycled on for 4 hours and cycled off for 2 hours.

From Aeration Basin #1, flow enters Aeration Basin #2.

Air in #2 is cycled on for 4 hours and cycled off for 2 hours.

From Aeration Basin #2, flow enters Aeration Basin #5 (note: the basins are numbered 1,2,5,6 with #3 and #4 being future).

Air in #5 is cycled on for 4 hours and cycled off for 2 hours.

The city is considering changes to the piping which will allow the internal recycling of flow from Aeration Basins #5 & #6 back to Aeration Basin #1 for improved nitrogen removal.

The city is also discussing options for accommodating additional industrial (food processing) waste flows.

Big picture take-aways

As modifications to the plant are being evaluated, it would be desirable to build in the flexibility for operating the aeration basins in parallel.

And, perhaps, look into retrofitting the four basins to work as sequencing batch reactors (SBRs), a proven technology that would provide Grand Forks with effective year-around total-nitrogen removal.

Can't state the following to be fact, but I suspect that Grand Forks' MBF clarifiers are the only ones I've seen during my visits to nearly 200 municipal mechanical wastewater treatment plants because other forms of clarification utilize far less electricity and chemicals.

I have seen DAF (dissolved air flotation) used in industrial applications and have operated such a facility myself.

Given that SBRs are typically designed with a hydraulic retention time of 24+/- hours, Grand Forks can convert the existing aeration basins to SBRs with little to no loss of capacity.

And.

If the aeration basins were converted to four parallel SBRs, perhaps the flocculator and/or MBF tanks could affordably be repurposed as side stream fermenters for biological phosphorus removal.

Phosphorus removal

As-is, I couldn't identify any low-cost options for phosphorus removal.

My favored strategy is that discussed above; that is, convert the aeration basins to SBRs and repurpose some of the no-longer needed fermentation and/or MBF tanks into side stream fermenters.

If this is of interest, I'd enjoy expanding the concept in future emails.

Another strategy is to install dividing walls in the existing aeration tanks to create anaerobic zones to serve as mainstream fermenters more or less in accordance with a design strategy that Grand Forks' engineers have discussed.

A consideration: aeration tank pH needs to be kept at 6.8 or higher for biological phosphorus removal.

Nitrogen removal

Given that aeration is currently cycled on and off in all of the in-service aeration basins, it's somewhat surprising that the effluent total-nitrogen values are as high as they are.

Tod and I discussed sampling protocols that should provide a better understanding of nitrogen removal and help identify options for improving nitrogen removal.

My suggestion: on three, ideally five, separate occasions, collect grab samples of wastewater going into and out of each in-service aeration basin.

Filter and test for ammonia, nitrate, and soluble BOD.

And.

Separately on three, ideally five, occasions … concurrent with the sample collection or different times altogether, it doesn't much matter … measure the DO at the end of an air-on cycle and at the end of an air-off cycle in each of the in-service aeration basins.

Even better, ORP if you have the capability.

Compile the data, review & discuss … I'd enjoy receiving a copy and being a part of the discussion if you'd like.

I suspect you'll find the following.

Actual data will be most informative.

I suspect you'll find the BOD leaving the first aeration basin to be too low to support denitrification (nitrate conversion to nitrogen gas) in any of the downstream aeration basins.

Meaning … that as ammonia is removed in the second and third aeration basins during the air-on cycles and converted to nitrate, there isn't enough BOD to push the nitrate to nitrogen gas during the air-off cycles.

Whereas the first aeration basin is likely operating differently.

In the first aeration basin, much of the nitrate that is produced as ammonia is removed is – I suspect – being converted to nitrogen gas during the air-off cycles because of the constant input of influent BOD.

Should my suspicions be true, the best fix is to operate the aeration basins in parallel more or less as they are now otherwise being operated.

Such an arrangement should have no impact on ammonia removal while boosting nitrate removal.

And, if it works out that way, eliminate the need for any internal recycling or baffling of aeration basins to create anoxic zones.

Another consideration: pH needs to be kept at 6.5 or higher for ammonia removal.

Gonvick MN

The following participated in our discussion:

Dan Johnson (Gonvick)

Randy Thorson (MPCA)

Grant Weaver (Grant Tech)

Treatment consists of a Walker Process package plant with two aeration zones, a central clarifier, and an aerated digester.

Plant flow averages approximately 30,000 gallons per day.

The attention paid to the treatment plant's performance during your every morning visits is evident.

The facility is well maintained and well operated.

At 6-7 mg/L, the aeration basin dissolved oxygen (DO) concentration is much higher than need be.

To reduce electrical expenses, I suggest reducing the blower speed by 2% a week until the DO reaches 2.0 mg/L or the ammonia concentration climbs to over 1.0 mg/L.

Another money savings recommendation is to cut back on the bacterial supplement.

I suggest adding the product on Monday, Wednesday and Friday only.

And.

If you don't see any adverse impacts after a month, my suggestion is to add a quarter-pound package of T197 Mega Bugs Plus twice per week.

Doing so will save almost $10.00 per week.

I'd like to see Gonvick put the money saved on electricity and bacterial supplements into testing equipment.

That is, I recommend you buy equipment so you can daily (M-F) measure effluent ammonia and nitrate in-house with either (a) test strips or (b) a Hach DR 900 as recommended by Rural Water.

And use the data to adjust aeration to optimize treatment as discussed below.

Nitrogen removal

During aeration, ammonia-nitrogen is converted to nitrate-nitrogen.

Gonvick is doing this really well.

To complete nitrogen removal, the nitrate-nitrogen needs to be converted to nitrogen gas.

I suspect that this isn't much happening as this final step happens in wastewater tanks with little to no dissolved oxygen.

Given that Gonvick has seasonal ammonia limits but no total-nitrogen limits …

and, given that the most restrictive ammonia limits are summer months …

I recommend forgoing any efforts at improving total-nitrogen removal until the fall when the ammonia limits are more lax.

This fall, when the ammonia limits are less restrictive, I recommend cycling the aeration equipment on and off to create alternating conditions with periods with the air-on long enough DO to support ammonia-nitrogen conversion to nitrate-nitrogen and periods with the air-off long enough to support nitrate-nitrogen conversion to nitrogen gas.

Start with an air-on cycle of 6 hours and an air-off cycle of 2 hours.

If ammonia climbs above 1.0 mg/L, return to continuous aeration and email or call me at **860.777.5256**.

After two weeks, call or email me with data and we can discuss the next settings:

if ammonia is less than 1.0 mg/L and nitrate is less than 5 mg/L, I'll recommend no change in the settings

if ammonia is less than 1.0 mg/L and nitrate is higher than 5 mg/L, I'll recommend extending the air-off time and/or shortening the air-on time

if ammonia is greater than 1.0 mg/L, I'll recommend shortening the air-off time and/or extending the air-on time

Between now and the fall, I suggest you purchase testing equipment.

And, when the equipment arrives, sample the effluent daily for ammonia and nitrate.

Record the data.

And share your findings with me before you begin adjusting the air-on/air-off times.

I also suggest you get the computer control system – SCADA, supervisory control and data acquisition – programmed to allow you to have air-on cycles of up to 12 hours and air-off cycles of up to 6 hours with the ability to adjust the cycles to increments of 15-minutes or less.

The Gonvick wastewater treatment plant should be able to meet whatever nitrogen limits MPCA puts into Gonvick's discharge permit without any further plant modifications.

Phosphorus removal

As big of a fan as I am of biological phosphorus removal, I don't think it worth the effort for Gonvick.

My suggestion is to chemically treat using an aluminum product such as alum, aluminum sulfate, or PAC (poly-aluminum chloride).

I'm hoping that Rural Water can help you select a product and dosage at which to feed it.

If not, a chemical supplier should be able and willing do so.

I'm thinking you'll want to purchase the produce in 35 or 55 gallon containers and to feed the product with a small peristaltic (preferred) or diaphragm pump.

MPCA

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By copy of this email, I'm asking Randy to have someone from MPCA advise you on how they'd like you to proceed with my recommendations (if at all) as there may be some paperwork involved.

Halsted MN

The following participated in our discussion:

Tony Wolf (Halstad)

Lucas Spaeth (Halstad), not present because of family health issues

Randy Thorson (MPCA)

Grant Weaver (Grant Tech)

Typical actual flow: 40,000-90,000 gallons per day

Influent BOD: 150-170 mg/L, not long ago was much lower: 70-90 mg/L

Effluent total-Phosphorus: 2.6 mg/L

Effluent Ammonia: zero, below the detection limit

Effluent total-Nitrogen: 21-22 mg/L

Effluent Nitrite+Nitrate: approximately 20 mg/L

Total-Phosphorus effluent limit: no limit currently but potentially 1.0 mg/L in future permits

Ammonia effluent limit: I failed to write this down

Total-Nitrogen limit: no limit currently but potentially 10 mg/L in future permits

Treatment consists of a 50,000-gallon aeration basin followed by secondary clarifier and disinfection.

Approximately 640 gallons of waste sludge is pumped twice weekly into a 10,000-gallon sludge storage tank.

The sludge storage tank is pumped out monthly.

With the support (encouragement?) of MPCA, Halstad has purchased land for the construction of a lagoon.

Being the penny pinching contrarian I am, I suggest re-evaluating the abandonment of the mechanical plant and constructing a lagoon.

The mechanical plant, I believe, can be made to remove nutrients (nitrogen and phosphorus) sufficiently to meet MPCA's near- and long-term nutrient limits.

And.

With a relatively small investment, the mechanical plant can be renovated sufficiently to provide effective wastewater service for decades.

Phosphorus removal

As discussed with Tony, a small change in how the plant is operated should provide effective phosphorus removal.

All that needs to be done is to return approximately ten percent of the sludge that is wasted into the sludge holding tank back into the treatment plant's aeration tank.

That is …

Since approximately 1280 gallons of sludge are wasted weekly, pump back 100-150 gallons weekly out of the non-aerated sludge holding tank and back into the aeration tank.

Here's why this will bring about phosphorus removal.

Sludge in the non-aerated sludge holding tank goes septic.

As it does, the food that the bacteria that remove phosphorus need to survive is formed.

Under septic conditions, the bacteria that remove phosphorus eat the food in the sludge holding tank and become energized.

Once the energized bacteria are pumped back into the aeration tank, they will multiply, and their population will increase.

As they grow (this happens only under aerobic conditions), they concentrate phosphorus inside their cells.

As they are wasted back into the sludge tank and eventually hauled away, the phosphorus leaves with the sludge.

Two factors to consider.

One, if you do as I suggest you will be putting some of the sludge back into the aeration basin, meaning you'll need to increase the volume of sludge wasted to keep the bacterial concentration in the aeration tank where you want it.

Two, the bacteria that remove phosphorus are slow growing; it may take a month or more for the effluent phosphorus concentration to drop.

Nitrogen removal

With a treated water ammonia concentration so low as to be undetectable, Halstad's wwtp couldn't do any better at removing ammonia-nitrogen.

That's the good news.

The bad news is the nitrogen is still in solution.

No longer as ammonia-nitrogen but now as nitrate-nitrogen.

But, more good news, bringing the nitrate down to a concentration that satisfies MPCA shouldn't prove that hard to do.

And.

Halstad should realize a small reduction in KWH of electricity used as nitrate-nitrogen is converted to nitrogen gas and escapes into the atmosphere.

(Air is ¾ nitrogen so the gas isn't polluting anything.)

To bring about total-nitrogen removal, simply cycle the air in the aeration basin on and off.

Enough air-on time to maintain effective ammonia removal.

Enough air-off time to develop effective nitrate removal.

Start conservatively by ensuring that there is always enough air-on time of high enough DO to remove ammonia sufficiently to maintain permit compliance.

Turn the air off for one hour in the morning and one hour in the afternoon.

This shouldn't make any difference in effluent quality, you shouldn't see any difference in treatment: nothing gets worse, nothing gets better.

After a week, extend the air-off cycles to two hours duration.

With two consecutive hours of off time, the nitrate-nitrogen concentration should begin to drop.

Using test strips, daily measure effluent ammonia to ensure that the air isn't off for too long.

Using test strips, daily measure effluent nitrate to monitor how effective the air-off cycles are working.

Continue making adjustments by (a) shortening the air-on cycles and/or (b) extending the air-off cycles.

Check in with me periodically by phone (860.777.5256) or email as I'm forever available to discuss air cycle settings with you.

MPCA

I'm glad Randy Thorson was present for the visit as I don't want you to cross wires with MPCA.

By copy of this email, I'm asking Randy to have someone from MPCA advise you on how they'd like you to proceed with my recommendations (if at all) as there may be some paperwork involved.

Hecla MB

The following participated in my visit:

Dave Collins (Hecla Provincial Park)

Ed Sexton (Hecla Provincial Park)

Grant Weaver (Grant Tech)

Treatment consists of an aerated multi-cell lagoon with a hydraulic retention time of approximately 100 days.

Alum is added for phosphorus removal.

Effluent is disinfected with chlorine (and dechlorinated) prior to discharge to Lake Winnipeg.

The lagoon experiences summertime blooms of vegetation.

As the vegetative material is removed, phosphorus – so I believe – is released, causing spikes in the phosphorus discharged as effluent.

With a fairly inexpensive instrument, the soluble phosphorus concentration can routinely be measured.

And.

The information used to ensure that enough, but not too much, alum is always added.

And, keep the facility permit compliant.

I recommend purchasing an orthophosphate colorimeter and test pillows such as the ones manufactured by Hanna, Hach, or LaMotte.

And putting the instrument into routine use.

https://www.hannainst.com/phosphate-high-range-portable-photometer-hi96717.html?gclid=CjwKCAjwzeqVBhAoEiwAOrEmzX1T42pIwe2cylxIwqUsGnH7ncviW2nK4s5x7ugO3H2f15xsDvcT6BoCTDoQAvD_BwE

https://www.neobits.com/hach_2106069_hach_21060_69_colorimeter_test_kit_p1754748.html?atc=gbp&gclid=CjwKCAjwzeqVBhAoEiwAOrEmzVRAylwbBbjtFGLFJe7rDpEUWKt7D21LUo6eaTB8rqCqD9Rc40aZ5BoCHmsQAvD_BwE_BwE

https://www.chemworld.com/LaMotte-Test-Kits-p/3242.htm?gclid=CjwKCAjwzeqVBhAoEiwAOrEmzX6dx1bXjY79226kot6VHJFzUZynxJXA6bUS21ewVY6X3Mui9I1yBRoCmZ8QAvD_BwE

Most instruments report orthophosphate in a form ("as PO4") that needs to be divided by three to equal "as P," what we in the world of wastewater use.

After purchasing an instrument, let me know what model and I'll confirm whether the results need to be divided by three to equate to the readings that your commercial lab provides.

My recommendation: weekly test the orthophosphate concentration in the effluent and, using this information, make adjustments to the alum dosage so that enough but not too much alum is added.

And.

Thereby ensuring ongoing compliance with the Park's effluent phosphorus limits without overdosing alum.

I wish I could provide advice on nitrogen removal as I understand this nutrient to be a concern.

But my expertise is mechanical wastewater treatment plants, not lagoons.

Selkirk MB

The following participated in my visit:

Raven Sharma (Selkirk)

Grant Weaver (Grant Tech)

The visit was a short one as Selkirk's one year old wastewater treatment facility is providing a high level of treatment.

Given that the purpose of my visit was to provide input on optimizing nitrogen and phosphorus removal, there was little to discuss.

Effluent total-phosphorus is typically 0.3 mg/L, one third of the permit limit of 1.0 mg/L.

This, even though the influent concentration is typically 12 mg/L.

Effluent total-nitrogen is typically 3-5 mg/L, very good numbers!

I enjoyed meeting you and hearing about Selkirk's new treatment facility.

If the time comes that you'd ever like to discuss operational issues, please call or email me as the Red River Basin Commission would like to see more facilities performing as well as yours.

<u>Portage la Prairie MB</u>

The following participated in our discussion:

Karly Friesen (Portage la Prairie)

Wyatt McEachnit (Portage la Prairie)

Brittany deNommeg (Portage la Prairie)

Justine, I didn’t get Justine’s last name (Portage la Prairie)

John, I didn’t get John’s last name (Portage la Prairie)

Grant Weaver (Grant Tech)

More than 50% of the wastewater flow is from food processing industries

More than 90% of influent nitrogen and phosphorus loading is from food processing industries

Influent total-nitrogen averages 96 mg/L, ranging from 88-120 mg/L

Influent total-phosphorus averages 20 mg/L

Effluent total-Phosphorus averages 17 mg/L

Effluent Ammonia is typically less than 0.3 mg/L

Effluent total-Nitrogen averages 71 mg/L

The BOD in the industrial flow is typically approximately 4,000 mg/L

The BOD in the municipal flow is typically approximately 135 mg/L

Currently there are no effluent limits for total-Phosphorus or total-Nitrogen

But nutrient limits are anticipated before the end of 2024 – tP: 1.0 mg/L, tN: 15 mg/L

I failed to write down what the ammonia limits are

Industrial flow passes through an anaerobic treatment “black box” that very effectively reduces BOD to low levels.

This flow is mixed with the municipal influent prior to treatment consisting of four sequencing batch reactors (SBRs).

All four SBRs are in service.

At current flows, the hydraulic retention time in the SBRs is many days … perhaps even a week.

Effluent is disinfected with UV prior to discharge.

The SBRs operate on eight-hour cycles consisting of ...

- 2 hour fill
  - 30 min (approximate) no air
    - 15 minute static
    - 15 minute mixed
  - 20 min (approximate) aerated
  - 45 min (approximate) no air
  - 5 min (approximate) aerated
- 1 hour react (aerated)
- 2 hour settle
- 50 minute decant
- 2 hr 10 min idle

Flow enters the bottom of the SBR tanks.

The city is receiving design-build-operate proposals for making the facility compliant with the nitrogen and phosphorus goals.

Including (do I have this right?) options for accommodating additional industrial (food processing) waste flows.

Observations / Comments / Recommendations

The industrial pretreatment system is overperforming; it is removing too much BOD.

Historically, this has been a good thing.

But.

Considerable BOD is required to drive biological nutrient removal.

Textbook values: 5 times as much BOD as nitrate, 25 times as much BOD as phosphorus.

Meaning …

For nitrogen removal, some 350 mg/L BOD needs to flow into the SBRs to fuel nitrate-nitrogen conversion to nitrogen gas during the air-off, anoxic cycles.

For phosphorus removal, some 425 mg/L of BOD needs to be available to the microbes that remove phosphorus … but not in the SBRs … in a side-stream fermenter … something to be explored at a future date.

Nitrogen removal

Given the many days of hydraulic retention time in the SBRs, I suspect that they could be operated to bring the total-nitrogen concentration down to the 15 mg/L target.

Nitrogen removal consists to two totally different environments; environments that SBRs are designed to provide.

First, ammonia-nitrogen is converted to nitrate-nitrogen in air-on / low-BOD conditions.

That is, during “react” aerobic cycles of the SBR.

Second, nitrate-nitrogen is converted to nitrogen gas (air ¾ nitrogen gas) during air-off “anoxic” cycles … whether mixed or static.

SBRs, therefore, remove nitrogen as follows.

Ammonia is converted to nitrate during the air-on cycles after the majority of the BOD is consumed.

This because BOD removing bacteria are faster growing than ammonia removing bacteria and will outcompete the ammonia removing bacteria for dissolved oxygen up until the BOD is essentially depleted.

After the soluble BOD is all but gone from the wastewater in the SBR, the BOD removing bacteria quit growing and therefor quit consuming oxygen.

At this point, the ammonia removing bacteria consume oxygen and, as they do so, convert ammonia to nitrate.

At the end of the batch, only 10-20 percent of the water volume is decanted and discharged; 80-90 percent of the nitrates therefore remain in solution.

Nitrate, then, is removed at the onset of the following batch as BOD rich influent flows into the SBR under no-oxygen “anoxic” conditions.

Two changes need to take place to optimize nitrogen removal in Portage la Prairie’s SBRs: more BOD entering the SBRs and stronger anoxic conditions as the BOD enters the SBRs.

See below.

(1) More BOD

The anaerobic treatment system needs to be “detuned” such that the BOD blend of municipal and industrial waste going into the SBRs is 300-400 mg/L.

(2) Boost Anoxic Conditions

Nitrate is removed under very low dissolved oxygen conditions with an abundance of soluble BOD.

Good news: the way flow enters the bottom of Portage la Prairie's SBR tanks is a real benefit for nitrate removal.

During static fill cycles, bacteria settle into a more compact sludge blanket providing more anoxic conditions with higher bacterial populations to feed on the incoming BOD (food).

Meaning …

To optimize nitrate removal and therefore produce an effluent with a lower total-nitrogen concentration, maximize the static fill time.

Potentially, operating with no air and no mixing during the entire 2-hour fill cycle.

Thoughts on how to implement improved nitrogen removal

Operate one fill cycle a day for a week with no air, no mixing.

Monitor conditions; that is, observe classical treatment conditions and daily test effluent ammonia and nitrate.

If no adverse impact, change programming so that all fill cycles for all SBRs has no air, no mixing.

Monitor conditions.

If after a month, no adverse impact, begin detuning the anaerobic "black box" so that somewhat less BOD is removed.

Slowly – over a period of months – further detune the anaerobic "black box" until effluent total-nitrogen drops below 15 mg/L.

Phosphorus removal

As staff become comfortable with the process changes made for nitrogen removal …

As staff become adept at controlling the process …

Begin exploring opportunities for biological phosphorus removal.

The best opportunities for biological phosphorus removal, as very briefly discussed during my visit, are likely the creation of a side stream fermenter by repurposing existing tankage.

A strategy I'd enjoy discussing with you if/when the time is right.