USER GUIDE – Optimization Methods and Best Management Practices for Facultative Lagoons

May 2015

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1.0 INTRODUCTION

In response to new numeric nutrient standards adopted by the Board of Environmental Review (BER), The Montana Department of Environmental Quality (MDEQ) commissioned a literature review of available technologies, Best Management Practices (BMPs), and optimization methods for increasing ammonia, total nitrogen, and total phosphorus removal efficiencies of facultative lagoon systems in Montana. It is anticipated that these new regulations will create compliance problems for facultative lagoon operators, as the new nutrient standards are significantly lower than previous levels or were not previously regulated. The final report titled *Literature Review – Optimization Methods and Best Management Practices for Facultative Lagoons* (WET, Geum 2015) *(Literature Review)* has been completed and is available for review at MDEQ.

This *Facultative Lagoon Optimization and Best Management Practices User Guide (User Guide)* has been prepared in coordination with the *Literature Review* document. While the *Literature Review* provides a comprehensive list of technologies and includes maintenance concerns related to wastewater lagoons, the *User Guide* summarizes a subset of operational, mechanical, and ecological technologies best suited and feasible for smaller Montana municipalities (Section 2). The *User Guide* also provides a Technology Selection Tool (Section 3) that will assist lagoon operators in the selection of the most promising improvements and technologies to assist with effluent compliance. The selection tool will guide operators through a series of questions that will provide a short list of technologies for further evaluation, as well as a ranking form that identifies major criteria that may drive final technology selection. A summary table of all technologies and BMPs is also included (Appendix A), along with contact information for specific technology providers (Appendix B). For more detailed information about each technology, please see the *Literature Review*.

The information in this *User Guide* and the companion *Literature Review* are intended to inform lagoon operators, engineers and other interested parties about the range of technologies available to improve water quality in wastewater lagoons. Both documents provide overviews and broad guidelines for each technology and are not intended for design and implementation. An engineer or other wastewater treatment professional should be consulted prior to final selection of a technology to determine specific design components appropriate for individual municipal resources. Design of a technology can greatly influence the cost and effectiveness of water quality improvement.

2.0 TECHNOLOGY SUMMARY

This section includes a brief summary of the technical literature evaluated for facultative lagoon optimization methods, technologies, and BMPs. This section is organized into three primary categories: Operational, Non-Mechanical, Mechanical, and Ecological. Each summary includes an overview of the specific technology or BMP, as well as general information on targeted parameters, expected removal efficiencies (if available), and capital/maintenance costs. For consistency throughout the document, parameters include Total Nitrogen (TN), Total Phosphorus (TP), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), and Ammonia. The term “nutrients” indicates that multiple parameters are

treated. A technology summary table was also developed and is included as Appendix A. A contact list of specific technology providers has been provided in Appendix C.

2.1 Operational Improvements

Operational activities include implementation of inspection, sampling, operation, or maintenance protocols that can lead to improved lagoon performance. This category includes an array of potential BMPs that do not require major design changes or capital expenditures. As a result, these improvements are generally more cost-effective; however, they may have limited treatment capabilities and removal efficiencies.

Ideally, operational improvements should be the first step in the lagoon optimization process. One-time or recurring maintenance or management improvements can have a significant impact on lagoon performance and may reduce or eliminate the need for significant capital improvements. *Wastewater Lagoon Troubleshooting: An Operators Guide to Solving Problems and Optimizing Wastewater Lagoon Systems*, as well as other DEQ and EPA documentation, were the primary resources consulted in the development of operational improvement strategies for lagoons.

2.1.1 Maintenance BMPs/Activities

There are several well documented maintenance activities and BMPs that should be part of a thorough routine maintenance plan for any facultative lagoon. These activities can include the following BMPs: sludge removal, vegetation control (aquatic and terrestrial), adjustment of flow patterns, burrowing animal control, infiltration/inflow, and others. Many of the major maintenance activities are included in this *User Guide* as standalone optimization BMPs. Completing routine maintenance of the system will help maintain treatment effectiveness and avoid potentially large capital replacement or maintenance in the future. Properly documenting all maintenance activities is critical for cost tracking, regulatory requirements, and proper planning.

2.1.1.1 Retention Times/Fill-Draw

Improving system performance by optimizing retention time and fill/draw schemes is a well-known and low cost operational BMP for lagoons; however, details and implementation are unique to each individual system. Multiple optimization strategies are available and can typically be managed as part of regular lagoon operations. Combining fill/draw adjustments with other technologies or BMPs available may also improve treatment. Longer detention times result in the decomposition of organic wastes and reduction of pathogens. Maintaining an effective pond depth is critical to overall system operation. Timing of fill and draw of ponds is critical to meet water quality objectives. Minimum and maximum depths must not be exceeded.

Issues Addressed: All Nutrients, TSS, BOD

Removal Efficiency: Varies significantly by site and may depend on incorporating additional technologies/BMPs
Relative Costs: Low
O & M: Low

2.1.1.2 Solid Waste Removal

Facultative wastewater treatment lagoons are intended to accumulate sludge to allow the biological decay of the settled material; however, too much sludge can negatively impact lagoon performance. The accumulation of solids in wastewater lagoons can affect effluent quality by reducing capacity and creating preferential flowpaths, thus reducing treatment efficiency. Lagoon sludge also releases nutrients that promote algal growth, and sludge may dislodge and enter the effluent; both adding to TSS and BOD in effluent streams. The objective for a treatment lagoon is to maintain the proper capacity for maximum treatment efficiency. Therefore, periodic sludge removal is required. Mechanical removal techniques are proven technologies that are fully scalable to varying lagoon sizes, easy to implement, require no additional land or permanent infrastructure, and are 100% effective at removing solids.

Issues Addressed: Nutrients, TSS, BOD
Removal Efficiency: Varies significantly by site and may depend on incorporating additional measures
Relative Costs: Medium
O & M: Low - (typically not required on an annual basis)

2.1.1.3 Reduce Influent

Facultative lagoon operators that are having problems with hydraulic overloading during wet weather events or suspect that significant infiltration is occurring due to deteriorated pipes or shallow ground water should conduct an Infiltration and Inflow (I&I) study. Most I&I enters the wastewater stream through the collection system, although lagoons do have the potential to allow inflow. Various proven I&I reduction techniques and approaches can be implemented to reduce non-sewage inflows to the wastewater system. Replacement of leaking infrastructure and several slip lining technologies are available that are effective in reducing non-sewage influent; these technologies are regularly used throughout Montana. However, depending on the magnitude of I&I, the cost of influent reduction may exceed the resulting additional cost of treatment. Site specific analysis should be conducted.

Issues Addressed: Indirect effect on nutrient removal - Nutrients, TSS, BOD
Removal Efficiency: Varies significantly depending on magnitude and extent of I&I
Relative Costs: Medium to High, depending on the extent of I&I
O & M: Low

2.1.2 Lagoon Covers

Lagoon covers can influence several factors associated with lagoons and ponds depending on the design and function of the pond. The main issues addressed specifically for facultative lagoons are the following: odor; algae (TSS); heat loss; evaporation; and birds/waterfowl. A cover can be a floating plastic cover, a synthetic or natural cover of peat, straw, or polystyrene, or HDPE floating balls or hexagonal tiles. The installation of synthetic covers ranges from expensive and laborious to simple and relatively inexpensive, depending on the type of cover and the purpose of the cover. Depending on what issues need to be addressed, the covers may need to be placed at different locations.

Two major types of synthetic covers are currently being used for facultative lagoons: floating membrane covers and hollow floating sphere/floating hexagon shaped tiles. Also, floating solar panels are an emerging technology that has the potential to be used in facultative lagoons in Montana. Some lagoon covers are compatible with other technologies such as floating barriers.

Issues Addressed: TSS (algae), odor, heat loss, evaporation, and waterfowl
Removal Efficiency: Ranges from 50% to 90% (TSS), varies for nutrients
Relative Costs: Low to high, depending on the type of cover
O & M: Low

2.1.3 Floating Barriers

Floating barriers can be used to create preferential flow patterns in water bodies to facilitate the conditions needed for all phases of the nitrogen cycle: ammonification, nitrification, and denitrification. Floating barriers, also called baffles, are designed to increase the retention time and settling time in water treatment lagoons to reduce total suspended solids and provide greater potential to enhance water quality treatment via aerobic and anaerobic processes that metabolize nutrients. Floating baffles/barriers are a relatively cost-effective method to optimize existing lagoon configurations with a more effective design that eliminates “short-circuiting” of wastewater flow.

Many companies create custom-designed floating baffle and curtain setups that fit the specifications of individual lagoons and can be installed on-site by independent contractors or local maintenance staff. Maintenance requirements are reasonable with regular inspection and maintenance required.

Issues Addressed: TSS, BOD, nutrients, retention time, mixing
Removal Efficiency: Varies significantly by site and may depend on incorporating additional technologies/BMPs
Relative Costs: Low to medium, depending on the type of barrier selected
O & M: Low

2.2 Mechanical Techniques

Mechanical improvements to facultative lagoon systems include the addition of lagoon infrastructure and/or treatment processes in order to improve performance. These technologies typically include moderate to major design changes and variable capital costs depending on the selected technology. They also may include increased operation and maintenance requirements which should be considered.

2.2.1 Aeration

Ammonia removal in facultative lagoons is generally achieved through algal consumption of ammonium; volatilization of gaseous ammonia to the atmosphere; and biological nitrification. Both volatilization and nitrification rely on mixing and oxygen in treatment lagoons. The rate at which ammonia volatilizes generally relies on the difference between ammonia concentration in the water at the lagoon surface and that in the atmosphere; therefore, mixing increases this rate by bringing water with higher ammonia concentrations to the surface and exposing it to the air. In the biological nitrification process, bacteria in the facultative and aerobic zones convert ammonia to nitrite, then nitrite to nitrate. Since oxygen is consumed during these reactions, and since many lagoon systems are not well mixed, the concentration of dissolved oxygen in the water column can be the limiting factor in the nitrification process.

Aeration is a commonly used method of oxygen delivery and lagoon mixing in wastewater treatment lagoons. Aerators and other systems can significantly improve treatment efficiency in wastewater lagoons that currently rely exclusively on natural processes such as wind for oxygen and mixing.

There are two main types of pond aerators: diffused aerators and mechanical aerators. Diffused aerators, or bottom aerators, transfer oxygen by injecting air bubbles. Oxygen is transferred across the surface of the bubbles and into the water. Mechanical aerators (or surface aerators) operate on the water surface and function by agitating the water to create small water droplets. Oxygen is transferred across the surface of the droplet from the surrounding air. Surface aerators may be applicable for use in existing facultative lagoons since they can be deployed to aerate the upper aerobic zone without introducing oxygen to the deeper anaerobic zone without introducing oxygen to the deeper anaerobic zone.

Issues Addressed: Ammonia, BOD, TSS, and odors
Removal Efficiency: Approximately 90% to 99% for ammonia, BOD, and TSS
Relative Costs: Medium
O & M: Low to Medium, depending on the design/product selected

2.2.2 Fixed-Film Bioreactors

Fixed-film biological systems have been used widely in the treatment of wastewater, particularly in the attainment of secondary effluent standards and nitrification. Biofilm systems continue to draw significant research attention. While this review is not an all-encompassing documentation for the biofilm processes, it does provide an opportunity

to reflect on what biofilm and hybrid biofilm systems may still have to offer the wastewater and environmental research and engineering community.

Fixed film reactor systems deliver a flexible, cost-effective, and easy-to-operate means to address current wastewater requirements and the expandability to meet future loads or more stringent discharge requirements within a compact design.

Issues Addressed: Nutrients, BOD, TSS, odors, and pathogens.
Removal Efficiency: Up to 95% (nutrients); 99% (BOD); and 99% (TSS).
Relative Costs: High to very high
O & M: Low to high depending on the technology

2.2.3 Phosphorous Removal

Phosphorus, nitrogen and carbon are essential to the growth of microorganism in surface water; phosphorus discharge is often the limiting nutrient in surface water. Excess phosphorus (eutrophication) may lead to algal blooms or undesired growth in surface water. In order to limit phosphorus discharge from a lagoon, there are several removal mechanisms:

1. Chemical precipitation;
2. Enhanced biological uptake;
3. Tertiary treatment; and
4. Activated Alumina Adsorption.

Phosphorus occurs in wastewater lagoons primarily as phosphates. Phosphates are organic, particulate (polyphosphate) and inorganic (orthophosphates) and are a component of aquatic organisms for growth. Naturally occurring bacteria known as phosphorus accumulating bacteria (PAOs) store excess phosphorous; some phosphorus is captured in the sludge and sediment in the bottom of the lagoon. However, standard facultative lagoons have minimal phosphorus attenuation and typically do not meet increased phosphorus removal regulations.

Stand-alone lagoon treatment (chemical precipitation and biological uptake) are proven methods to reduce phosphorus levels below 1 mg/L total phosphorus. Chemical precipitation typically includes metals salts such as aluminum sulfate (alum), ferric chloride or ferrous chloride. Other chemical additives include lime, or polymers. Biological uptake may include harvesting of wetland plants, and aerated biofilm treatment with storage for high phosphorus waste streams. A general class of this treatment method is called enhanced biological phosphorus removal (EBPR). Additional end-of-lagoon treatment may be required to further reduce effluent levels; additional filtration after lagoon settling may reduce TP to 0.5 mg/L and chemical addition with a sand filter may reduce TP to levels below 0.02 mg/L.

Issues Addressed: Total Phosphorous

Removal Efficiency: Up to 99%
Relative Costs: Medium to High
O & M: High

2.2.4 Alternate Carbon Sources/Denitrification

The reduction of total nitrogen is a two-step process. The first step, the conversion of ammonia to nitrite and then to nitrate, is called nitrification. The nitrification process is mediated by the bacteria, which require an aerobic environment for growth and metabolism of nitrogen. The second step of the process, the conversion of nitrate to nitrogen gas, is referred to as de-nitrification. This process is also mediated by bacteria. For de-nitrification to occur, the dissolved oxygen level must be at or near zero. The bacteria also require a carbon food source for energy and conversion of nitrogen. The bacteria metabolize the carbonaceous material or biological oxygen demand (BOD) in the wastewater as this food source, metabolizing it to carbon dioxide. This in turn reduces the BOD of the sewage, which is desirable. However, if the sewage is already low in BOD, as is the case in the nitrification/de-nitrification process, the carbon food source will be insufficient for bacterial growth and de-nitrification will not proceed efficiently. To overcome this problem, the system must incorporate an external source of organic carbon to achieve nitrate removal.

It is recommended that in external carbon sources, specifically solid carbon sources, be evaluated on a site-by-site basis to determine if they could be combined with additional technologies to enhance total nitrogen removal. Complimentary technologies include aeration, floating covers, floating islands, and other ecological technologies.

Issues Addressed: Total Nitrogen
Removal Efficiency: Up to 95%
Relative Costs: Medium to High
O & M: Medium to High

2.3 Ecological Approaches

2.3.1 Constructed Wetlands

Wetlands are an effective means for treating wastewater after lagoon treatment. Wetlands require no mechanical components such as pumps and maintenance requirements are low. Overall cost is low and primarily upfront related to construction.

Three primary hydraulic designs for constructed wetlands include: vertical flow, horizontal subsurface flow, and surface flow. In vertical flow wetlands wastewater is distributed across the top of the wetland and percolates vertically through the soil and/or gravel media. In subsurface flow wetlands, plants are installed in a gravel media. Wastewater enters at one end of a wetland, often through a filtering media such as coarse gravel, and moves horizontally though the submerged soil and plant root matrix. Waters exit the wetland at the opposite end of the wetland from which it entered. In

surface flow wetlands, wastewater enters the wetland at one end and moves to the other end flowing between plant stems, above the soil surface.

Of the three types of wetlands, vertical wetlands generally provide an aerobic environment best suited for treating ammonium. Subsurface flow wetlands primarily provide an anoxic environment, but can also contain aerobic environments. Thus, these wetlands have the potential to treat both ammonium and ammonia. Surface wetlands can also be constructed for phosphorus removal enhancement. Surface wetlands (less commonly used for treating wastewater) primarily provide an anoxic environment best suited for treating ammonia. All wetlands will store phosphorus initially, but removal will decline with time.

Wetlands are best suited for municipalities with available land (acreage will depend on effluent volumes). Wetlands work best during the growing season and specifically in temperatures above approximately 5°C (approximately 41°F). Because of this wetlands may be best paired with other treatments or management strategies such as storage of wastewater during colder seasons or a mechanical technology that is effective in cold weather.

Issues Addressed: Nutrients, TSS, BOD
Removal Efficiency: Varies by design
Relative Costs: Medium
O & M: Low

2.3.2 Vermiculture

Vermiculture is a relatively new technology where earthworms are used to aerobically treat wastewater and waste products similar to the common composting technique used in gardening that also involves earthworms. Water quality benefits include reduction of toxins, neutralization of metals and nutrient processing. Maintenance is minimal and costs related to the technology are primarily up front when purchasing earthworms, constructing composting chambers or investing in patented designs. Pumps will be required to separate sludge from wastewater. Two variations of vermiculture are referenced in the literature. Vermicompost refers specifically to solid waste and vermifiltration to wastewaters. Vermiculture is most applicable for municipalities looking to reduce N and BOD levels with populations between 500 and 10,000 residents. Additional space is required to install pumps and composting chambers. The effectiveness of vermiculture in colder climates in the U.S. has not been tested. However, cold is not as large of a concern as heat. Additionally, the company Biofiltro reports operation of a Chile facility located in an area that receives snow.

Issues Addressed: Nutrients, BOD, TSS, metals, coliform bacteria, pathogens, toxins
Removal Efficiency: Up to 99% (BOD); 90% (TSS); 99% (metals)
Relative Costs: Medium to High
O & M: Low

2.3.3 Vegetation Harvesting

Harvesting algae or duckweed is a relatively new technology but has been shown to be effective at removal of various nutrients such as P and N, and for BOD and TSS. Algae and duckweed harvest is most effective at N removal. Mechanical components are needed for harvesting vegetation. Maintenance tasks include production and harvesting of algae or duckweed. Although algae and duckweed can produce desirable products such as biofuels and compost, harvesting and converting algae and duckweed can be costly. There are several techniques for harvesting algae and duckweed. Some of the most common are flocculation, floatation, and centrifugation. Temperature and pH are two of the main environmental variables important to sustain algal and duckweed growth. Another important factor is maintaining an adequate nutrient supply that supports vigorous algae or duckweed biomass production. For wastewater treatment, algae and duckweed harvest is recommended as a secondary or tertiary treatment. Because production is low in colder climates, vegetation harvesting may be best paired with other treatments or management strategies such as storage of wastewater during colder seasons or mechanical technologies effective in cold weather.

Issues Addressed: Nutrients, BOD, coliform bacteria, metals, pathogens
Removal Efficiency: Up to 68.4% (BOD); 86% (N); 97.8% (P)
Relative Costs: Low
O & M: High

2.3.3 Floating Islands

Floating islands are an established technology with potential to enhance water quality treatment in wastewater lagoons via aerobic and anaerobic processes that metabolize nutrients. Floating islands are buoyant mats that are most often planted with vegetation but can also be unvegetated. The mats float on a water surface and when planted, plant roots are exposed to the water column. Floating islands are capable of removing nutrients of concern from wastewater lagoons particularly N. Phosphorus, BOD and TSS are also reduced. Pollutant removal is generally higher in vegetated islands because the root systems support microbial communities that will process nutrients. Floating islands have demonstrated a 20 to 40% increase in nutrient removal over free surface lagoons. Floating islands can be used toward the end of a lagoon system with multiple ponds and thus do not require additional land. Floating Islands require no mechanical components such as pumps and maintenance requirements are low. Overall cost is low and primarily upfront related to construction or purchase of a floating island through a distributor. Various floating island designs exist including a simple square or circular island. To improve performance, the floating island can be donut shaped and aeration can be added to the open center. Floating islands can also be constructed as boardwalks improving access to maintain the vegetation as well as open areas appropriate for aeration and methods to increase wastewater contact time with the vegetation. Floating islands work best during the growing season and specifically in temperatures above approximately 5°C (approximately 41°F). Because of this floating islands may be best paired with other treatments or management

strategies such as storage of wastewater during colder seasons, mechanical technologies that are effective in cold weather, or fish.

Issues Addressed: Nutrients, BOD, TSS
Removal Efficiency: Varies by design
Relative Costs: Medium to High
O & M: Low

2.3.4 Terrestrial Application

Terrestrial application of wastewater is a water purification technology that has been used for many years and is most efficient at reducing N concentrations. It can produce final effluent with concentrations lower than 2mg/L for BOD and TSS, less than 3mg/L for N and less than 0.1mg/L for P. Terrestrial application requires an irrigation system, but is otherwise low tech. Maintenance is largely related to harvesting vegetation if applicable and is otherwise minimal. Overall cost is low and primarily upfront if purchasing an irrigation system or leasing land. Cost can potentially be redeemed if productive vegetation such as timber or forage is harvested. Three primary methods of terrestrial application are used: soil aquifer treatment which provides water purification via deep, filtering soils; slow rate application involving harvesting vegetation; and overland flow application which involves collecting wastewater effluent after it passes through low profile vegetation such as grass that is not harvested. Overland flow is not permitted in Montana. Irrigating with nutrient rich wastewater effluent can produce higher crop yields and economically beneficial resources. Terrestrial application of wastewater is applicable to municipalities with access to larger plots of land or who may be able to partner with other landowners particularly farmers or ranchers. Terrestrial application of wastewater effluent can be practiced in both warmer and colder climates, although it would be necessarily seasonal in colder climates. Alternatives for terrestrial application during colder months include converting the wastewater to snow if consistently colder temperatures exist or simply storing within existing lagoons if feasible.

Issues Addressed: Nutrients, BOD, TSS, metals, coliform bacteria and pathogens
Removal Efficiency: Varies by design
Relative Costs: Low
O & M: Medium

2.3.5 Other

2.3.5.1 Fish

The use of fish for wastewater purification appears to be effective. Water quality benefits include a reduction in nitrogen and phosphorus when fish are harvested. Maintenance is low and relates mainly to harvesting fish. This is a viable technology for municipalities with no available land because fish can be directly introduced into existing lagoons. Pairing the use of fish with, and after, other technologies may be most beneficial to reduce high nutrient

concentrations that may harm and kill fish. At the very least it may be best to use fish in final lagoons where nutrient levels are lowest. Harvesting fish could provide economically beneficial resources via the conversion of fish to pet food or compost. For lagoons in Montana, water depths would need to be deep enough (12 to 15 feet) to ensure a portion of the lagoon does not freeze over the winter providing overwintering habitat.

Issues Addressed: Nutrients, BOD
Removal Efficiency: Up to 11% (TN); 6% (TP)
Relative Costs: Low
O & M: Medium

2.3.5.2 Eco-Machines

An Eco-Machine™ can be described as an artificial ecosystem of plants, microscopic algae, fungi, bacteria, protozoa, zooplankton, snails, clams, and fish working in combination within distinct treatment zones. The incorporation of various treatment techniques makes Eco-Machines™ a flexible technology for both water treatment goals and administrative constraints. Treatment techniques can include wetlands, floating islands, greenhouses, ecological Fluidized Beds, mycro-reactors and clarifiers. Targeted pollutants will vary with the treatment techniques selected. Maintenance requirements for Eco-Machines™ are minimal, and may be concentrated within the first year or two of operation while operational strategies develop and plants establish. Eco-Machines™ are generally a more expensive and elaborate option for wastewater treatment for smaller municipalities in Montana; although, where applicable, this technology could be an attractive educational tool for the public in addition to a wastewater treatment facility. A variety of components included in Eco-Machines™ perform best during the growing season. Additional components, specifically greenhouses, can ensure year ground performance of wastewater treatment.

Issues Addressed: Potential to process all pollutants depending on design
Removal Efficiency: Varies by design
Relative Costs: High
O & M: Medium

3.0 Lagoon Optimization/BMP Selection Process

The selection process to determine the most appropriate technology/technologies is not a “one size fits all” approach. Each lagoon in Montana has specific site conditions that may suggest the use of certain technologies (available space to land apply effluent) or preclude the use of others (lack of available space prevents addition of wetland cells). Although there are several lagoon technologies that are likely to be successful at most sites (aeration, fixed film, phosphorus removal, etc.), other factors may limit their implementation (financial capacity of community, power requirements, maintenance needs, etc.).

From an operational improvement standpoint, the activities and BMPs detailed in Section 2.1 are generally applicable and should ideally be conducted on all facultative lagoons, as appropriate, in contrast to new technologies that may only be appropriate in some cases. This report simply identifies the various operation and maintenance improvements available. As a result, the implementation of these BMPs should not necessarily be a "selection", but part of an overall evaluation of a facility to determine if certain operational and maintenance activities can be added to annual routines. A lagoon operations checklist could be developed to easily identify what operational activities are currently being conducted, and those that could be added to improve performance.

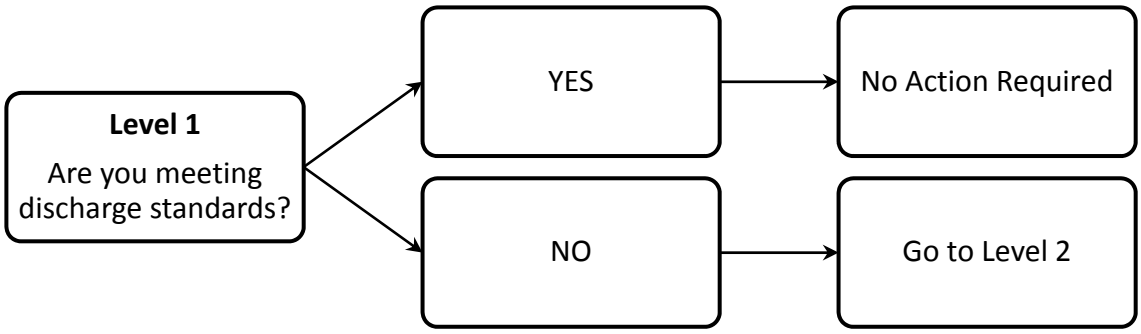
3.1 Technology Screening Tool

If operational improvements are not sufficient to bring the lagoon discharge into compliance, then an operator must move forward with evaluating mechanical and/or ecological technologies that will increase nutrient removal efficiency. A *Technology Screening Tool* was developed to guide operators through a series of questions that will identify the most applicable technologies based upon their site specific conditions. These questions are divided into four "levels" in order to allow operators to take incremental steps toward technology implementation. This approach focuses on identifying simple operational technologies as options before moving into more expensive mechanical or ecological technologies that require significant capital investment and higher levels of operation and maintenance.

The *Technology Screening Tool* is illustrated on the following pages, with supporting narrative to more clearly identify the screening process.

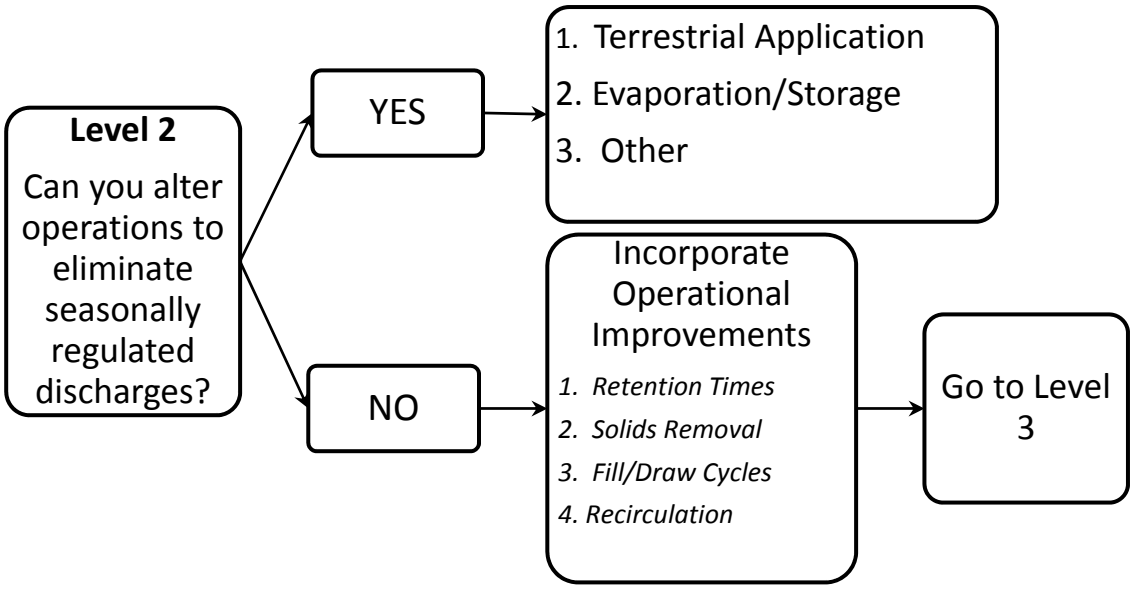
Level 1

Level 1 of the screening tool asks the most basic question regarding the lagoon: "Are you meeting the discharge standards for your facultative lagoon?" If the answer is "Yes" then no further action is required. However, if any discharge standards are not being met, you must proceed to Level 2.



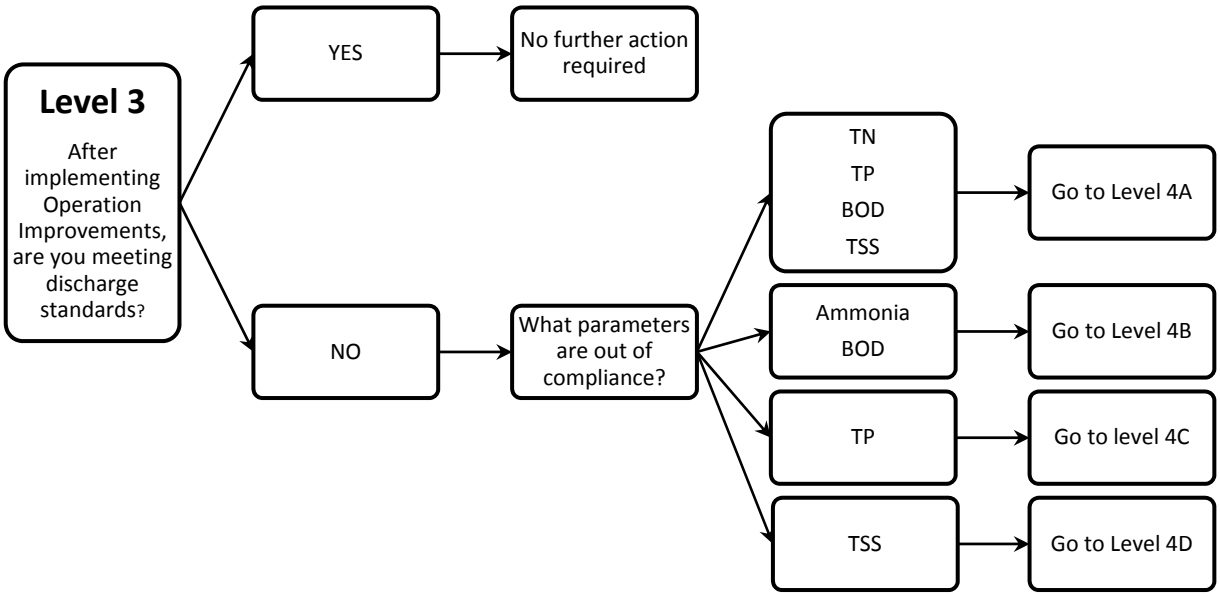
Level 2

Level 2 addresses the potential for an operator to alter their lagoon operation and remove discharge during regulated time periods. Level 2 asks the question "Can your lagoon system operations be altered to eliminate seasonally regulated discharges?" If the answer is "Yes" then alternate designs such as land application, evaporation/storage systems, or seasonal discharges should be evaluated. If the answer to Level 2 is "No" and the lagoon system cannot be operationally altered to eliminate discharges, then implementation of operational BMPs is recommended. These BMPs include activities such as adjustment of retention times, maintenance activities such as sludge removal, maximizing efficiency by determining the best fill/draw cycles, and/or the potential for recirculation. Implementation of these operational BMPs should include consultation with a design engineer to ensure that adjustments fall within the design parameters of the lagoon and to ensure maximum water quality improvement. After operational BMPs are implemented, proceed to Level 3.



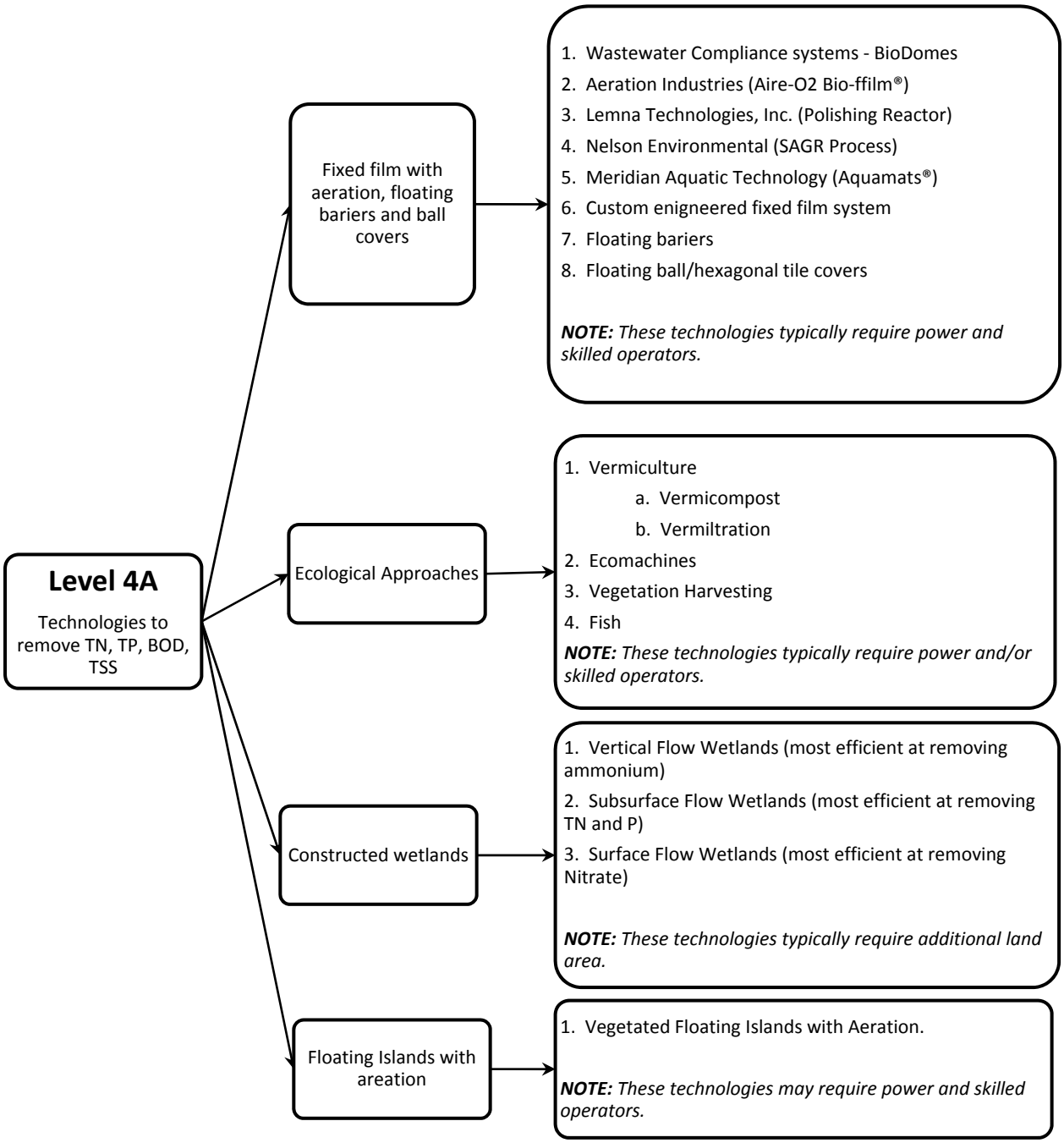
Level 3

Level 3 identifies whether discharge standards are being met after operational improvements. If the answer is "Yes", no further action is needed. If the answer is "No", the operator must proceed to Level 3. Level 3 identifies which water quality parameters are out of compliance. This guides the operator to a specific list of technologies identified in Level 4 that are most effective for that specific parameter/parameters. If the lagoon requires treatment for TN, TP, BOD, and TSS proceed to Level 4A. If only ammonia and BOD require treatment, proceed to Level 4B Evaluation. If only phosphorous is out of compliance, proceed to the Level 4C Evaluation. If TSS is out of compliance, proceed to the Level 4D Evaluation.



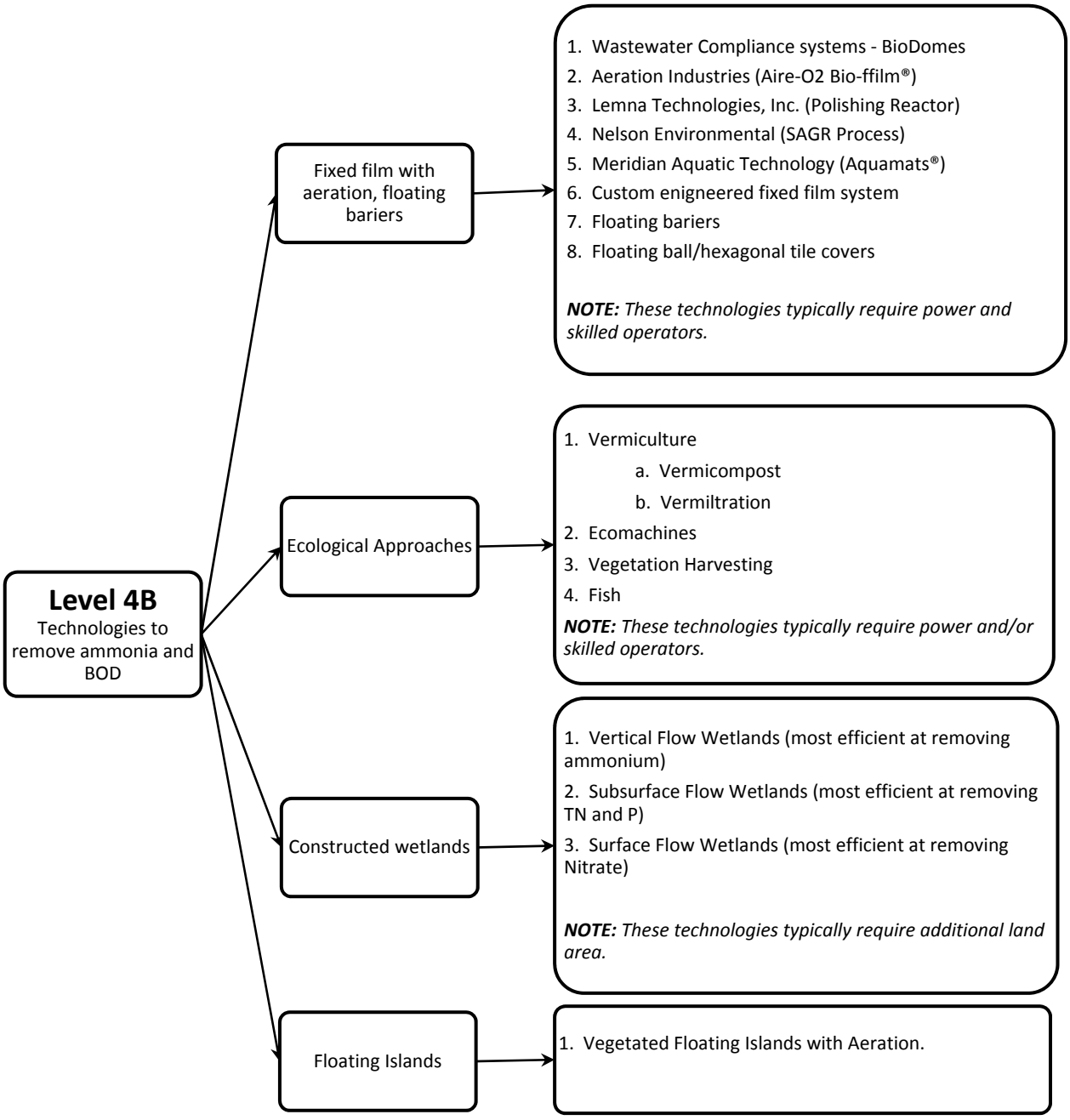
Level 4A

Level 4A identifies several technologies that may be appropriate to treat TN, TP, BOD, and TSS. These technologies then can be further evaluated using the *Technology Ranking Matrix* listed in Section 3.2. The potential technologies include: fixed film reactors with aeration; constructed wetlands with aeration; floating islands with aeration; and chemical precipitation. Examples of specific technologies are included in the subsequent flow chart. It is important to note that many of the available technologies in Level 4A may require additional land; a reliable power source; and/or skilled operators.


Level 4A
Technologies to remove TN, TP, BOD, TSS
Fixed film with aeration, floating bariers and ball covers
1. Wastewater Compliance systems - BioDomes
2. Aeration Industries (Aire-O2 Bio-ffilm®)
3. Lemna Technologies, Inc. (Polishing Reactor)
4. Nelson Environmental (SAGR Process)
5. Meridian Aquatic Technology (Aquamats®)
6. Custom enigneered fixed film system
7. Floating bariers
8. Floating ball/hexagonal tile covers
NOTE: These technologies typically require power and skilled operators.
Ecological Approaches
1. Vermiculture
a. Vermicompost
b. Vermiltration
2. Ecomachines
3. Vegetation Harvesting
4. Fish
NOTE: These technologies typically require power and/or skilled operators.
Constructed wetlands
1. Vertical Flow Wetlands (most efficient at removing ammonium)
2. Subsurface Flow Wetlands (most efficient at removing TN and P)
3. Surface Flow Wetlands (most efficient at removing Nitrate)
NOTE: These technologies typically require additional land area.
Floating Islands with areation
1. Vegetated Floating Islands with Aeration.
NOTE: These technologies may require power and skilled operators.

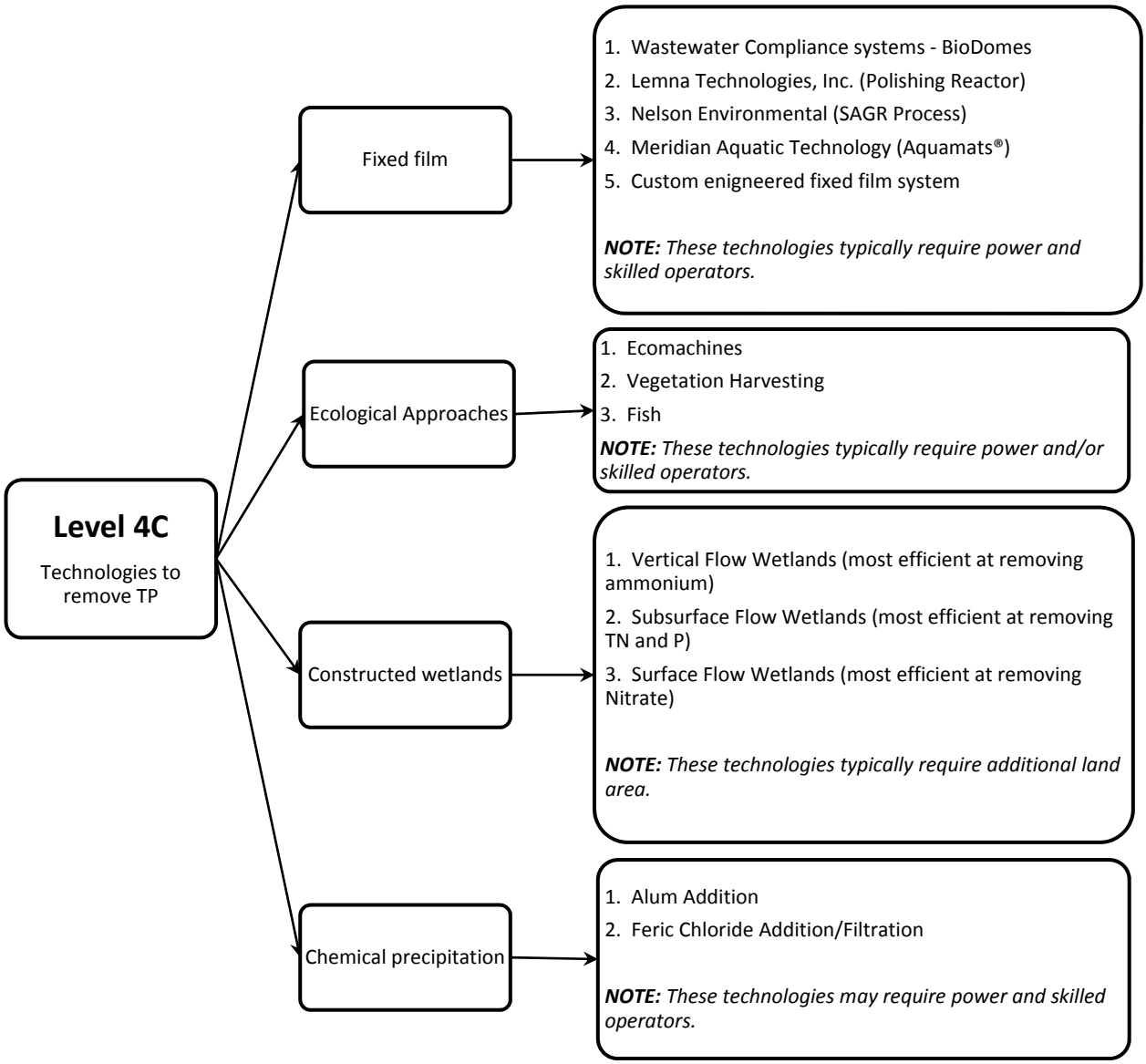
Level 4B

Level 4B determines what technologies are focused on treatment of ammonia and BOD. These technologies then can be further evaluated using the *Technology Ranking Matrix* listed in Section 3.2. The potential technology areas include: Fixed film reactors with floating barriers; constructed wetlands with aeration; and floating islands with aeration. Examples of specific technologies are included in the subsequent flow chart. It is important to note that many of the available technologies in Level 4B may require additional land; a reliable power source; and/or skilled operators.



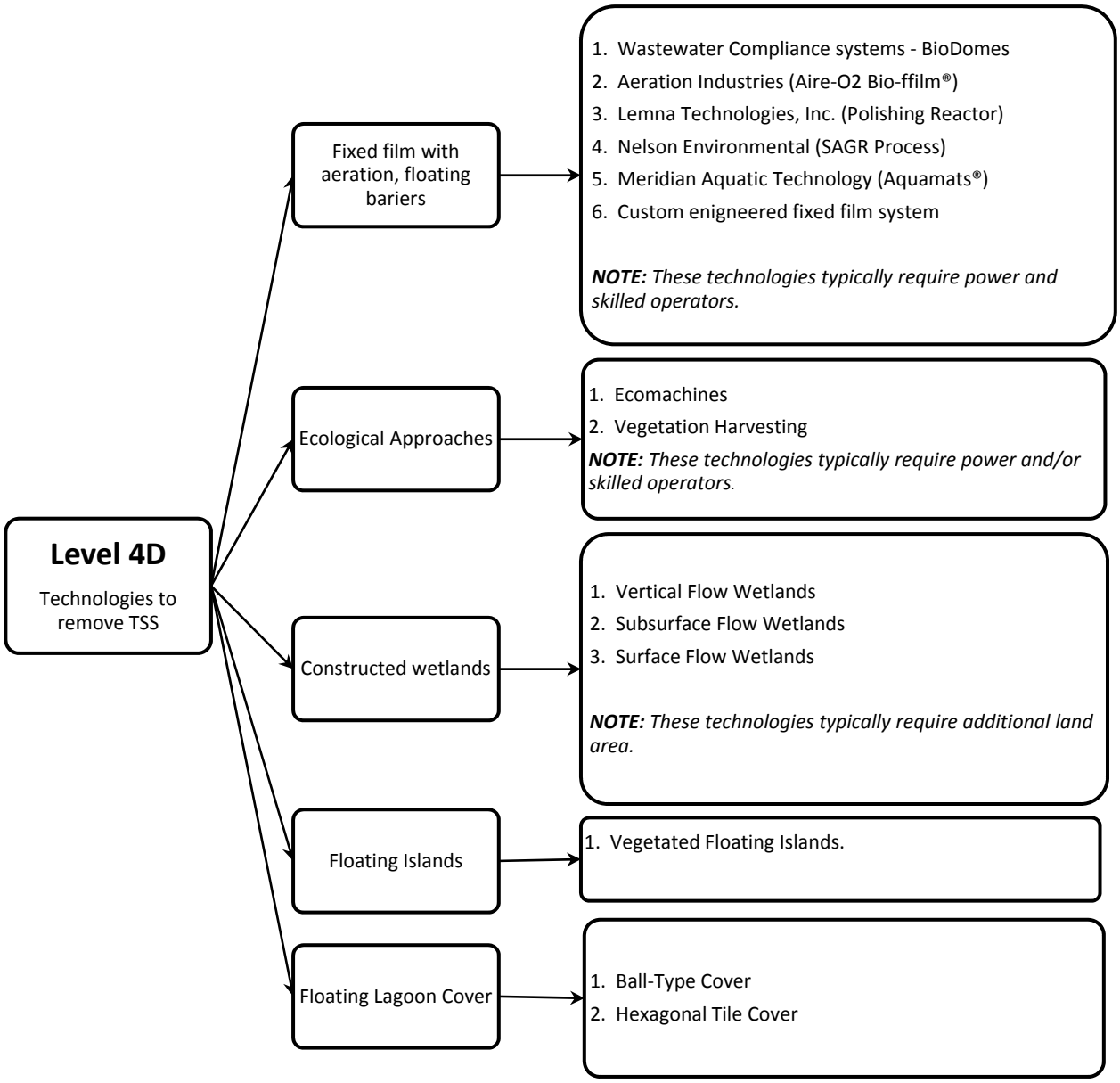
Level 4C

Level 4C determines what technologies are focused on treatment of only phosphorous. These technologies then can be further evaluated using the *Technology Ranking Matrix* listed in Section 3.2. The potential technology areas include: Fixed film reactors; constructed wetlands; and chemical precipitation. Examples of specific technologies are included in the subsequent flow chart. It is important to note that many of the available technologies in Level 4c may require additional land; a reliable power source; and/or skilled operators.



Level 4D

Level 4D determines what technologies are focused on treatment of only TSS. These technologies then can be further evaluated using the *Technology Ranking Matrix* listed in Section 3.2. The potential technology areas include: Fixed film reactors with floating barriers; constructed wetlands with aeration; floating islands with aeration; and floating lagoon covers. Examples of specific technologies are included in the subsequent flow chart. It is important to note that many of the available technologies in Level 4d may require additional land; a reliable power source; and/or skilled operators.



3.2 Technology Ranking Matrix

Once the screening tool has identified a "short-list' of technologies, lagoon operators can use the *Technology Ranking Matrix* to further evaluate and rank technologies. This matrix is an excel-based ranking matrix that will calculate technology scores based on specific inputs entered by the user. Operators should consult with their contracted engineer or wastewater professional to discuss site specific conditions and design parameters that may affect technology selection.

Populating the Technology Ranking Matrix

The selected lagoon optimization technologies/BMPs from Section 3.1 should be entered across the top of the matrix as shown in the example at the end of this section. The selected technologies will be identified in the Level 4 evaluation of the Technology Screening Tool. It is assumed that the Operational Improvements described earlier this document will be employed prior to or in conjunction with the specific upgrade technologies

Identify Design Criteria

The design criteria are intended to help determine which identified technology/BMP will best serve the needs of the community. These key criteria were identified as generally the most important factors to consider in lagoon optimization design. The ranking matrix is structured so that a high score for each criterion represents a favorable result and a low score represents an unfavorable result. Design criteria are listed down the left side of the matrix but can be changed or added to by the user to reflect site specific conditions and values within the municipality that are not included here.

The following criteria have been identified for facultative lagoon upgrade projects:

1. Capital Costs
2. Operation and Maintenance Costs
3. Expected Removal Efficiency
4. Design Flexibility/Implementation
5. Land Requirements
6. Power Requirements/Availability
7. Operator Skill Requirements
8. Public Opinion

Assign Criteria Weighting

Decision/selection criteria are also weighted to represent which criteria are most and least important to the project. Weights are assigned to each decision criteria, with the total combined weight not to exceed 100%. Weightings have been assigned to the identified design criteria in the matrix; however, weightings can be adjusted by the user to reflect site specific conditions.

Assign Scores to the Design Criteria

The user will then assign a score for each design criteria for each technology that is being ranked. The matrix scoring system is scaled from 1 to 5, with 1 being the lowest (worst) and 5 being the highest (best). The technology summaries in Section 2.0 and the Technology Summary Matrix in Appendix A provide information that can be used as a basis for assigning scores. **The user may want to consult with their design engineer or other wastewater professional in order to ensure accurate scoring. A scoring guide is listed below for each design criterion:**

1. Capital Costs

   Rating: 1 = Highest Cost
   2
   3 = Moderate Cost
   4
   5 = Lowest Cost

2. O & M Costs

   Rating: 1 = Highest Cost
   2
   3 = Moderate Cost
   4
   5 = Lowest Cost

3. Removal Efficiency/Performance

   Rating: 1 = Does not remove all, Low removal efficiency
   2
   3 = Removes specific parameters, but not others
   4
   5 = High efficiency removal of all parameters

4. Design Flexibility/Implementation

   Rating: 1 = Least Flexible (significant new design/construction, increased footprint, etc.)
   2
   3 = Moderate design/retrofit required
   4
   5 = Most Flexible (Can be easily implemented within existing configuration)

5. Land Requirements

   Rating: 1 = Significant Additional Land Requirement
   2
   3 = Minimal land requirements
   4
   5 = No additional land required

6. Power Requirements/Availability

   Rating: 1 = 3 Phase power required, Distance >1-mile
   2

3 = Power required minimal/solar
4
5 = No additional permanent power requirement

7. Operator Skill Requirements
   Rating: 1 = Significant skills/part-time-full-time operator required
   2
   3 = Additional skill/time commitment required
   4
   5 = No additional skills required

8. Public Opinion
   Rating: 1 = Very significant opposition
   2
   3 = No significant opposition or support
   4
   5 = Overwhelming community support

Ranking Project Alternatives

The technologies are scored by multiplying the rating for each design criterion by its weighting factor. The scores are then totaled for each technology being considered. These scores can further identify which technology/BMP may be the most applicable and successful for a site. The selected technology/BMP should be evaluated further by a design engineer prior to implementation. A sample Technology Ranking Matrix is included on the following page.

User Guide Example

An example Technology Ranking Matrix is included below. The example matrix has been populated with the following technologies:

Technology 1 (T-1): Fixed Film: SAGR Process.
Technology 2 (T-2): Fixed Film: Lemna Polishing Reactor with floating ball cover.
Technology 3 (T-3): Fixed Film: Bio-Domes.
Technology 4 (T-4): Constructed Wetlands.
Technology 5 (T-5): Floating Islands with Solid external carbon source.

Selection Criteria		Weight	PROJECT ALTERNATIVES				
			T-1	T-2	T-3	T-4	T-5
	1. Capital Costs *Rating: 1 = Highest Cost* *2* *3* *4* *5 = Lowest Cost*	20	Rating: 3 Score: 60	2 40	3 60	3 60	5 100
	2. O & M Costs *Rating: 1 = Highest Cost* *2* *3* *4* *5 = Lowest Cost*	15	Rating: 4 Score: 60	2 30	2 30	4 60	1 15
	3. Removal Efficiency/Technical Feasibility/Performance *Rating: 1 = Does not remove all, Low removal efficiency* *2* *3 = Partial parameter removal* *4* *5 = High potential for removal of all parameters*	20	Rating: 5 Score: 100	4 80	4 80	2 40	1 20
	4. Design Flexibility/Implementation *Rating: 1 = Lest Flexible* *2* *3* *4* *5 = Most Flexible*	15	Rating: 5 Score: 75	4 60	4 60	3 45	2 30
	5. Land Requirements *Rating: 1 = Significant Additional Land Requirement* *2* *3* *4* *5 = No additional land required*	15	Rating: 3 Score: 45	4 60	4 60	1 15	5 75
	6. Power Requirements/Availability *Rating: 1 = 3 Phase power required, Distance >1-mile* *2* *3 = Power required minimal/solar* *4* *5 = No additional permanent power requirement*	5	Rating: 3 Score: 15	3 15	3 15	4 20	4 20
	7. Operator Skill Requirements *Rating: 1 = Significant additional skills required* *2* *3* *4* *5 = No additional skills required*	5	Rating: 3 Score: 15	3 15	3 15	4 20	4 20
	8. Public Opinion *Rating: 1 = Very significate opposition* *2* *3* *4* *5 = Overwhelming community support*	5	Rating: 3 Score: 15	3 15	3 15	4 20	5 25
	TOTAL SCORE	100 Weight	385 T-1	315 T-2	335 T-3	280 T-4	305 T-5

Appendix A – Technology Summary Matrix

FACULTATIVE LAGOON TECHNOLOGY MATRIX

Treatment	Water Quality Function	Ancillary Benefits	Risks/Other Considerations	Dependencies	Complimentary treatments	Capital Cost	Maintenance Requirements	Footprint	Examples in Montana	Effective in low temperatures	Patent
EXAMPLE - TECHNOLOGY A	*• Reduces N* *• Reduces BOD* *• Functions as a catalyst for X*	*• Ancillary benefits*	*• Potential risks associated with the example treatment that may increase management levels, be a health concern, etc.*	*• Other treatments the example treatment requires to function*	*• Treatments that would work well in conjunction with the example treatment*	*Low ($), Medium ($$), High ($$$), Very High ($$$$)*	*None/Low/Med/High*	*No Increase/ Moderate increase/ Large increase*	*Yes/ No*	*Yes/No*	*Yes/No*
OPERATIONAL											
Retention Times Fill/Draw	• Improves removal efficiency of P, N, BOD, TSS, metals, coliform bacteria, and pathogens	• Increases retention time • Reduces short-circuiting • Facilitates optimal treatment depths	• Effluent water quality must be monitored.	None	All operational BMPs can be combined with other lagoon optimization technologies	$	Low	No Increase	Yes	Yes	No
Solid Waste Removal	• Improves removal efficiency of P, N, BOD, TSS, metals, coliform bacteria, and pathogens	• Increases capacity • Minimizes wet weather problems and overflows	• Damage to lagoon liner • Scouring of lagoon embankments	None	All operational BMPs can be combined with other lagoon optimization technologies	$$	Low	No Increase	Yes	Yes	Yes - Numerous existing and patented technologies
Reduce Influent	• Minimizes sewer overflows • Improves removal efficiency of P, N, BOD, TSS, metals, coliform bacteria, and pathogens	• Saves capacity • Eliminates wet weather problems and overflows	• Cost/benefit of reducing influent should be carefully evaluated.	None	All operational BMPs can be combined with other lagoon optimization technologies	$$ to $$$$	Low	N/A	Yes	Yes	Yes - some sliplining technologies are patented
Mosquito Control	• No significant treatment of primary pollutants	• Public health benefits	• Chemicals used can be harmful to other insects and aquatic habitat if not applied properly, and repeated use could cause resistance.	None	Mowing of vegetation along embankments, vegetation harvesting	$ to $$	Low	N/A	Yes	No	Yes - Some treatment technologies (Larvasonic)
Maintenance Schedule/Activities	• Improves removal efficiency of P, N, BOD, TSS, metals, coliform bacteria, and pathogens	• Ancillary benefits are dependent on specific maintenance activity	None	• Identification of proper maintenance activities and schedules may require monitoring and technical evaluation. •Activities require varying levels of operator time and skill to be effective.	All operational BMPs can be combined with other lagoon optimization technologies	$	Low-High	No Increase	Yes	Yes	No
MECHANICAL											
Aeration	• Removal of Ammonia-N, nitrite, TSS, & BOD. • Improves TSS breakdown by mixing.	• Odor reduction if applied appropriately.	Risk of oxygenating anaerobic zone.	None	Aeration can be used with most lagoon optimization technologies.	$$$	Low-Med	No Increase	Yes	Yes	Yes, Numerous existing and patented technologies.
Lagoon Covers	• Reduces TSS • Provides insulation to maintain higher temperatures, thereby increasing lagoon efficiency	• No impediment to aeration equipment pond; • Prevent UV light penetration & surface oxygenation, maintaining anaerobic conditions; • Quick and simple to install; • Spread automatically as the liquid levels rise and fall; • Deters birds from landing on the lagoon and contributing N • Virtually indestructible UV resistant HDPE material; • Cannot tear like conventional membrane covers; and • Can freeze into ice covered lagoons without damage.	None	None	Lagoon covers can be used with most lagoon optimization technologies.	$ to $$$	Low	No Increase	Yes	Yes	Yes
Floating Barriers	• Reduces TSS • Improves BOD and prevents lagoon short-circuiting • Compatible with other technologies.	• No impediment to aeration equipment pond; • Quick and simple to install; • Virtually indestructible UV resistant HDPE material; • Can freeze into ice covered lagoons without damage; • Automatically adjusts to changes in water volume;	None	None	Floating Barriers can be used with most lagoon optimization technologies.	$ to $$$	Low	No Increase	Yes	Yes	Yes
Fixed Film Bioreactors • Fixed Media Systems o Trickling filter o Rotating Biological Contactor (RCB) o Packed Bed (Fixed Bed) Reactors o Submerged Aerated Reactors • Suspended (Free Floating) Media Systems o Moving Bed Bio-Reactors (MBRR) o Fluidized Bed Reactors	• Reduces Ammonia • Reduces Total Nitrogen • Reduces BOD • Reduces TSS • Reduces Total Phosphorous • Nitrification • Denitrification	• It is stable under load variations, insensitive to temporary limitation and provides consistent treatment results. • It generates low solids and requires no or minimum polymer for solid/liquid separation. • It requires a small footprint compared to other processes. Typically it requires 1/3rd the space required for Activated Sludge Process. • It requires a low capital cost and is comparable to cost of Activated Sludge Process. It is cheaper than the MBR process. • Existing wastewater plants can be upgraded easily with many fixed film technologies. New fixed film plants can be upgraded to handle higher loads with no or minimum cost and construction. • It is easy to operate, has automatic sludge wasting, has no sludge Return and no MLSS, and there no issue of media clogging. • Capacity can be easily upgraded by simply increasing the fill fraction of biofilm carriers. • No return activated sludge stream required. • Actively sloughed biofilm automatically responds to load fluctuations.	• Groundwater and/or drinking water contamination.	Varies depending on the reactor configuration and/or the required treatment.	Fixed Film Bioreactors can easily be incorporated with most other identified lagoon optimization technologies.	$$$ to $$$$	Low-High, depending on the system and the treatment needs.	No Increase to Potential increase to existing pond modification.	Yes	Yes	Yes, Numerous existing and patented technologies.

Activated Sludge	• Reduces Ammonia • Reduces Total Nitrogen • Reduces BOD • Reduces TSS • Reduces Total Phosphorous • Nitrification • Denitrification	• It is stable under load variations, insensitive to temporary limitation and provides consistent treatment results. • Existing wastewater plants can be upgraded easily with many fixed film technologies. New fixed film plants can be upgraded to handle higher loads with no or minimum cost and construction. • Actively sloughed biofilm automatically responds to load fluctuations.	• Groundwater and/or drinking water contamination.	The Activated Sludge process is a complete system that requires many components to work effectively.	The Activated Sludge process is a complete system that requires many components to work effectively.	$$$$$	Very High	Potential increase or redesign of existing footprint	Yes	Yes	Yes, Numerous existing and patented technologies.
Phosphorus Removal • chemical precipitation; • enhanced biological uptake; • tertiary treatment; and • Activated Alumina Adsorption.	• Permanent removal of P.	• Provides diverse aquatic and terrestrial habitat.	• Groundwater and/or drinking water contamination.	• Previous water quality treatment.	Can be an add-on technology to numerous identified technologies.	$$ to $$$	High	No Increase	Yes	Yes	Yes, Numerous existing and patented technologies.
Alternate Carbon Sources	• Removal of TN (Denitrification)		• Groundwater and/or drinking water contamination.	• Must have nitrified wastewater in an anaerobic environment.	• Aeration, Activated Sludge, Fixed Film	$$ to $$$	Med-High	No Increase	Yes	Yes	Yes, Numerous existing and patented technologies.
Pathogens/Disinfection	• Permanent removal harmful pathogens.		• May harm beneficial microorganism colonies.	• Previous water quality treatment.	Can be an add on technology to numerous identified technologies.	$$	Med	No Increase	Yes	Yes	Yes, Numerous existing and patented technologies.
ECOLOGICAL											
Constructed Wetlands	• Vertical wetlands primarily address NH_4^+. • Subsurface wetlands primarily address NH_4^+ and NO_3^-. • Surface wetlands primarily address NO_3^-. • All wetlands are effective at addressing BOD and TSS. • P is stored in plant tissue and sediments.	• Provides diverse aquatic and terrestrial habitat.	• N may increase as a result of water fowl use. • Mosquitoes. • Odor. • Invasive plant species.	• Previous water quality treatment.	N/A	$$	Low	Large	Yes	No	No
Floating Island	• Effective at NH_4^+ removal under aerated conditions. • Effective at NO_3^- removal without aeration. • P is stored in plant tissue and sediments. • Reduction of TSS.	• Provides diverse aquatic and terrestrial habitat.	• Sulphide toxicity. • Increased ice formation. • Potential to attract waterfowl. • Invasive plant species.	• Previous water quality treatment.	• Aeration	$$ to $$$	Low	No Increase	Yes	No	Yes
Vegetation Harvesting	• Permanent removal of P, • Removal of N, BOD, TSS, metals, coliform bacteria, and pathogens	• Can be used as livestock feed, poultry feed, compost or biofuel.	• Toxic types of blue-green algae may grow with duckweed. • Some harvesting methods can contain heavy metals, limiting reuse options.	• Previous water quality treatment.	N/A	$	High	No Increase	No	No	No
Terrestrial Application	• Removal of P, N, BOD, TSS, metals, coliform bacteria, and pathogens	• Can provide lumber or forage or other economic resources.	• Groundwater and/or drinking water contamination.	• Previous water quality treatment.	N/A	$	Med	Large	Yes	Yes	No
Vermiculture	• Removal of N, BOD, metals, coliform bacteria, chemicals and pathogens	• Can provide compost.	• By products of vermicomposting may contain toxins and pathogens. • High temperatures will kill earthworms.	N/A	N/A	$$ to $$$	Low	Moderate	No	Yes	Yes
Fish	• Permanent removal of P. • Removal of N and BOD	• Harvested fish can be used as pet food or compost.	• Die off may occur if pollutant levels are too high.	• Previous water quality treatment.	N/A	$	Med	No Increase	No	Yes	No
Eco-Machines™	• Capable of processing all pollutants depending on the included components.	• Can be an educational resource and/or tool.	• Depends on included components.	N/A	N/A	$$$	Med	Moderate to Large	No	Yes	Yes

Appendix B – List of Technology Providers

LAGOON UPGRADE TECHNOLOGY PROVIDERS and PATENTS

NOTE: This technology provider list is not all-inclusive and is not intended to be a recommended or preferred list. Other providers/products may be available and appropriate within each category.

Aeration

- Triplepoint Water Technologies
  http://www.triplepointwater.com/lagoon-technologies/mars-wastewater-lagoon-aeration/#.VVY32flVhBc

- Lenntech Water Treatment Solutions
  http://www.lenntech.com/aeration.htm

- Airmaster Aerator
  http://www.airmasteraerator.com/aerator-pond-aeration.html

Constructed Wetlands

- None (All wetlands require site specific designs)

Eco-Machines

- John Todd Ecological Design
  http://www.toddecological.com

Fixed Film

- Wastewater Compliance systems – BioDomes
  http://wastewater-compliance-systems.com/products

- Aeration Industries (Aire-O2 Bio-ffilm®)
  http://aireo2.com/

- Lemna Technologies, Inc. (Polishing Reactor)
  http://www.lemnatechnologies.com/lemnaPolishingReactor.php

- Nelson Environmental (SAGR Process)
  http://www.nelsonenvironmental.com/sagr/

- Meridian Aquatic Technology (Aquamats®)
  http://www.paradisenw.com/aquamats_filtration.php

- EDI (IDEAL™ Solution)
  http://www.wastewater.com/lagoon-solutions/ideal-solution

- FBC Technologies, Inc. (Bio2Bloc®)
  http://www.fbctech.com/

- Triplepoint Water Technologies, LLC (NitrOx™)
  http://www.triplepointwater.com/

- ENTEX Technologies (BioWeb™)
  http://www.entexinc.com/solutions/bioweb/

Fish

- Live Fuels, Inc.
  http://www.livefuels.com

Floating Barriers

- Elastec American Marine
  http://www.elastec.com/baffles/

- Engineered Textile Products
  http://www.etpinfo.com/floating-baffle-curtain/Floating-Baffle-Curtain-Mississippi-Gulf-Coast.pdf

- Environetics, Inc.
  http://www.environeticsinc.com/FloatingBaffle.htm

- The Environmental Company: Wastewater Treatment Solutions.
  http://www.ebac2000.com/baffle.htm

- Nelson Environmental, Inc.
  http://www.nelsonenvironmental.com/optaer/lagoon-baffles.asp

Floating Islands

- Floating Island International Inc.
  http://www.floatingislandinternational.com

- John Todd Ecological Design
  http://www.toddecological.com

- TECH-AI® (patent)

- Biohaven® (patent)

Lagoon Covers

- Advanced Water Treatment Technologies (AWTT)
  http://www.awtti.com/index.php

- LEMNA Technologies, Inc.
  http://www.lemnatechnologies.com/

Vermiculture

- Biofiltro USA, Inc.
  http://biofiltro.com

Vegetation Harvesting

- Algaeventure Systems, Inc.
  http://algaevs.com

- Algae to Energy, LLC
  http://www.algae-to-energy.com

- Partitioned Aquaculture System (patent)

Appendix C – Selection Criteria Spreadsheet (Electronic)

(Available as a Microsoft Excel spreadsheet)