Swan Lake Remediation and Resource Recovery SL$(R)^3$
Engineering Science Capstone Design Project

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Abstract

The Swan Lake attraction at Brookfield Zoo is continually in a eutrophic state every year as a result of nutrient loading. This abundance of nutrients caused by goose droppings leads to an excess growth of duckweed and watermeal. The dissolved oxygen of the lake decreases drastically as a result of these plants covering the lake's surface, restricting oxygen exchange between the lake and the open air and preventing sunlight from reaching underwater plants that produce dissolved oxygen, thus endangering the fish population. It is crucial to remove the duckweed in order to reduce nutrient levels and increase the dissolved oxygen in the lake.

Figure 1: Current lake status in the summer when covered in duckweed

Figure 2: Close-up look at texture of duckweed and watermeal

Introduction

Background

Brookfield Zoo (BFZ), managed by the Chicago Zoological Society (CZS), is home to over 450 different species of animals on more than 200 acres of land, providing a family-friendly atmosphere for education and adventure to people throughout the Midwest. The mission of CZS is to inspire conservation leadership by people and communities with wildlife and nature. One attraction found at BFZ is Swan Lake. Swan Lake is a 4-acre lake that is home to geese, ducks, turtles, and swans and has a peaceful nature trail around its perimeter.

What is Duckweed?

- Scientific name: *lemnoideae minor*
- World's smallest flowering plant
- Grows on the surface of water, grows wide rather than deep
- Capable of doubling its biomass in 24 hours under ideal conditions
- Requires sun exposure, eutrophic water conditions, and stagnant water to thrive
- Blooms from May to October in Illinois
- Can grow to be about 2-5mm long and 1.5-3.5mm wide
- Prevents oxygen exchange, therefore decreasing dissolved oxygen levels in the water

System Description

The system used to skim duckweed from the lake's surface is broken down to five main sections: collection method, intake, filter, transport, and reuse. The system is made up of multiple components, including the intake, pump, inflow, filter, catch container, and outflow.

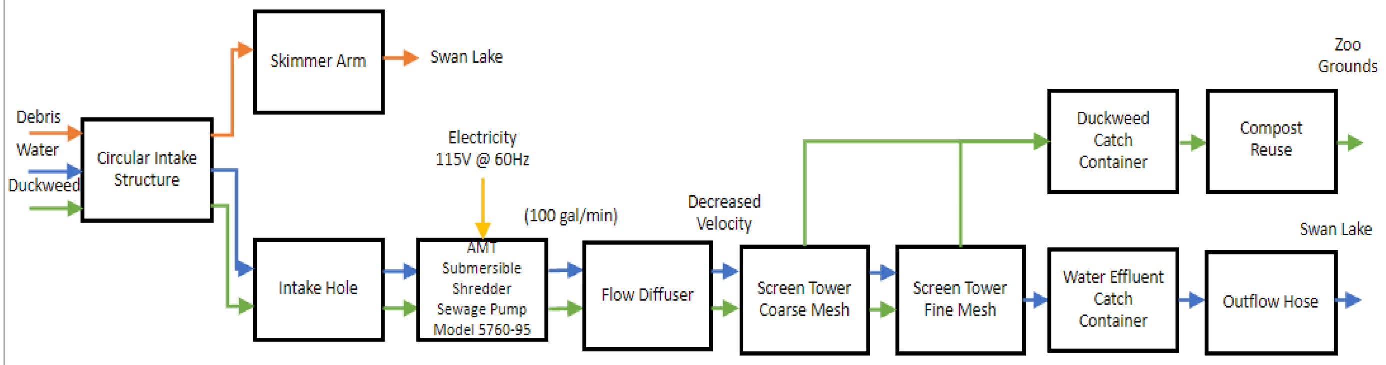

Figure 3: System Diagram of Swan Lake skimmer system detailing the flow of debris, water, and duckweed

Scope of Work

Phase 1: Collection System Improvements

- Analyze current system's harvesting capabilities, storage capacity, ease of use, and long-term sustainability
- Analyze lake water quality to determine current and target water conditions
- Design an improved duckweed collection system
- Build a benchtop prototype of collection system design solution
- Conduct a lifetime cost analysis of proposed solution
- Research key water regulations which constrain the design and device operation

Phase 2: Resource Recovery and Reuse

- Examine the current treatment system to determine feasibility of resource recovery
- Analyze existing resource recovery technologies
- Research potential applications of recovered resources from harvested biomass
- Design a resource recovery and reuse system
- Conduct a lifetime cost analysis of proposed solution
- Research key water regulations which constrain the design

Figure 4: Current filtering system involving a hose, mesh, and catch container

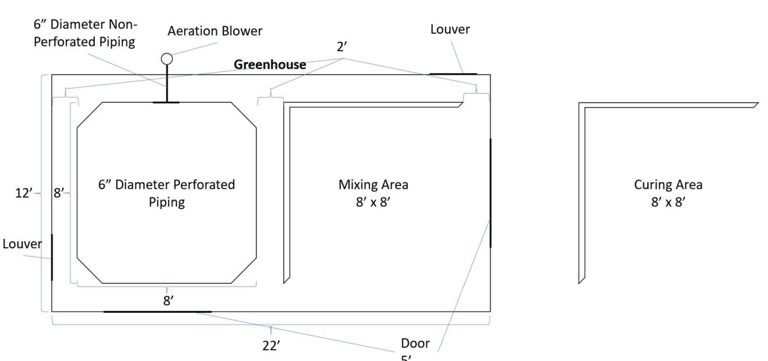

Figure 5: Proposed resource recovery and reuse greenhouse blueprint

Methods

Nutrient Data Analysis

The Brookfield Zoo first began removing duckweed biomass from Swan Lake in the summer of 2019. System improvements in 2020 resulted in large reductions in nutrient concentrations. By increasing the amount of duckweed biomass removed from the lake, the nutrient concentration will decrease, and the duckweed growth will become self-limiting due to lack of nutrients. Comparing month to month nutrient concentrations from 2019 and 2020 show significant decrease in nitrogen concentrations once the active removal of duckweed began.

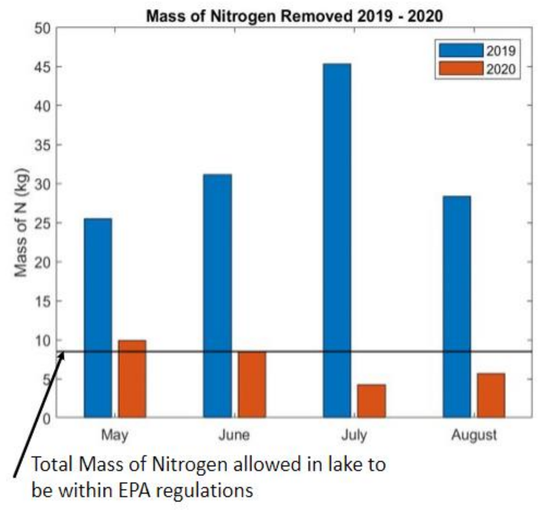

Figure 6: Bar graph depicting difference in nitrogen levels between 2019 and 2020 after skimming duckweed from Swan Lake

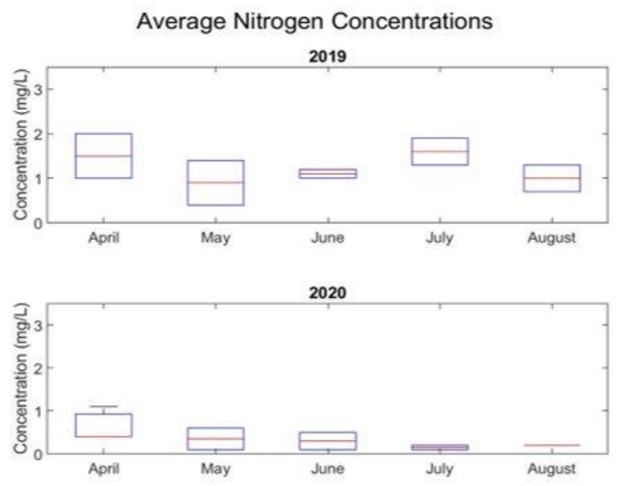

Figure 7: Box plot depicting difference in nitrogen concentrations between 2019 and 2020 after skimming duckweed from Swan Lake

Design Process

Numerous decision-making tools were utilized when brainstorming potential designs for an improved skimming system, providing justifications for specific design choices at each stage. The team implemented the morph matrix, design criteria and justifications, Pugh Matrices, and failure modes and effects analysis to reach the ultimate skimmer design.

The result of this decision-making process is the eventual design comprised of the active collection system attached to a small boat, omni-directional intake with an intermittent wiper to prevent clogging, angled layer screen tower to separate the biomass from the lake water, gravity slide to transport duckweed between locations, and in-place composting of duckweed and watermeal for resource recovery and reuse.

Prototyping and Testing

Models of various design aspects were developed in SOLIDWORKS, prototype models were built using available materials, and calculations were conducted to determine how to best scale down the skimmer system for off-site testing. Additionally, a risk analysis was performed on significant modes of failure and new controls were created to minimize risk and failure.

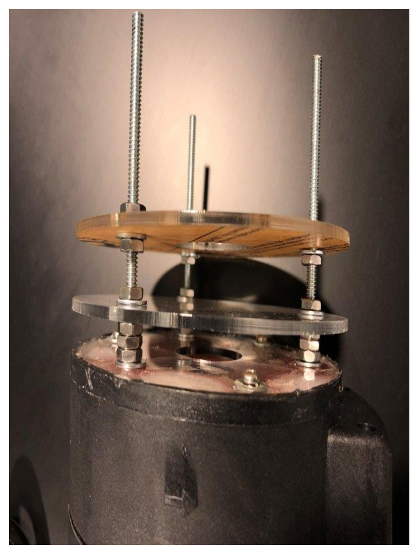

Figure 8: Scaled-down prototype pump and intake

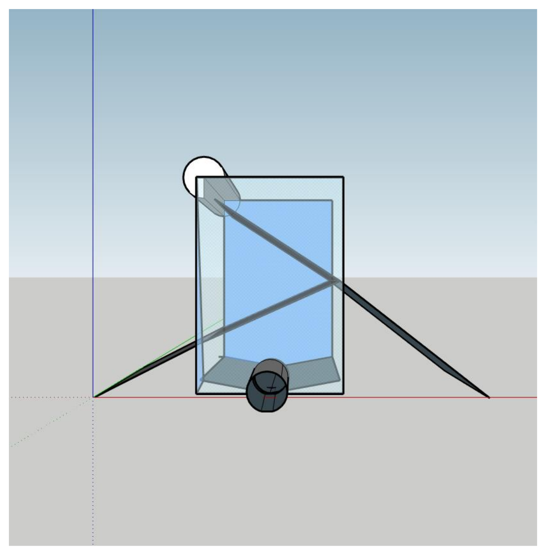

Figure 9: SOLIDWORKS diagram of angled layer screen tower for filtering

Collection Method: Active collection system attached to a boat

The collection method was simulated by calculating the amount and frequency of duckweed harvesting from Swan Lake in order to allow the plant life to self-limit its growth. Using MATLAB, a script was developed to theoretically determine how duckweed could be used as a sponge to absorb nutrients from the water that led to its growth.

Intake: Omni-directional intake with intermittent wiper

The team calculated specifications for a scaled down pump, purchasing a smaller pump to use for simulations and prototyping. A triple-plate schematic was conceived to improve skimming capabilities and prevent clogging. Using nuts and bolts and laser-cutting acrylic, the scaled-down pump was outfitted with the new intake design and tested in an inflatable pool with floating pieces of debris to simulate duckweed.

Filter: Angled Layer Screen Tower

Using two sheets of different sized mesh and stainless-steel framing bars, a prototype multi-layered screen tower was made to filter the duckweed out from the lake water. While the current prototype holds two screens, it can be improved to manage three or four screens of successive mesh size from coarse to fine. A flow diffuser was also constructed to distribute the flow across the full area of the screen and reduce its velocity.

Transport: Gravity Slide and Wheelbarrow Container

The angled screens and wheelbarrow containers beside the screen tower would be used to transport the duckweed between locations. Ideally, the resource recovery site would not be far from the source of collection, so hauling the wheelbarrow to the site should not be too labor-intensive. The layers are angled to 45 degrees, so the screens become self-cleaning, and the system becomes more autonomous as the wheelbarrows have a large capacity.

Resource Recovery and Reuse: In-Place Composting

The proposed method of resource recovery and reuse for the harvested duckweed is in-place composting. This involves air flow through and over a stagnant pile of biomass which would be mixed with carbon sources, like woodchips and dry leaves, to balance the nitrogen-to-carbon ratio for more efficient composting.

Results

Final Design

Building prototypes and conducting tests for proof-of-concept shed a light on some minor logistical issues. Obstacles like how and where to test were solved by constructing a scaled-down prototype to test on-campus for proof-of-concept. After testing the prototype in a kiddie pool, the current pump in use was outfitted with the same intake structure and tested on-site at the zoo. Another challenge was the growing season of duckweed. Since the plant did not bloom during the time this project was conducted, materials such as Styrofoam, frozen vegetables, leaves, and old dried duckweed were used as proxies for the actual plant.

Proposed Resource Recovery and Reuse

The proposed plan of in-place composting for harvested duckweed could be an entire project on its own. The team's proposal involves the construction of a greenhouse-type structure that involves aeration tubes with blowers and biofilters based on the zoo's old composting facility. The team has taken the compost manual from the previous facility and updated and shortened it to accommodate for duckweed and reduced equipment and labor requirement for the proposed plan. A potentially expensive undertaking, the idea can also be simplified to just a roof over the pile of biomass but could require more manual labor to ensure that there is enough airflow and no pungent odors that can be emitted during the composting process.

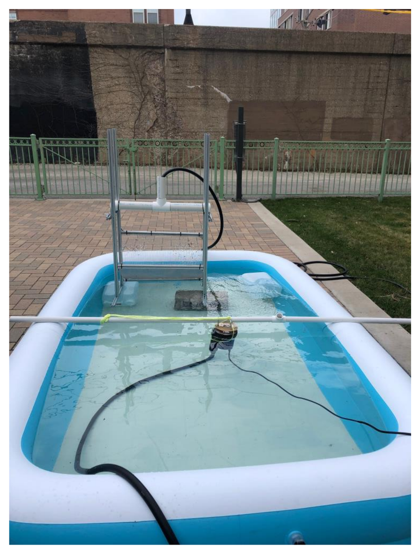

Figure 10: On-campus testing setup with scaled prototypes

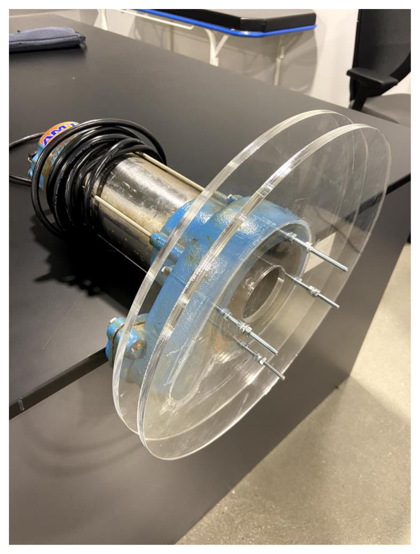

Figure 11: Full-size shredder pump with multi-plate intake attached

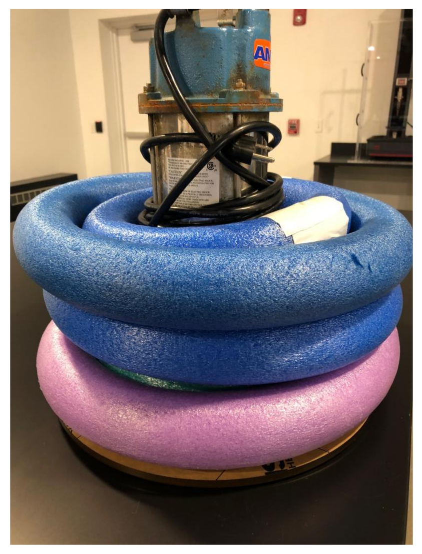

Figure 12: Full-size shredder pump with prototype pool-noodle buoyancy device

Discussion

Lessons Learned

This project taught the team a lot about project management, decision-making processes, and duckweed control. Documentation of files like timesheets and meeting minutes were crucial to keeping everyone on task and accountable, as well as the importance of ensuring all documents are backed up to the cloud in case of emergency. A lot of different decision-making tools and strategies were used to help make quantified and justifiable choices in the design process.

Next Steps

- Expand on resource recovery and reuse to further uphold the zoo's mission statement
- Improve upon the proposed composting system
- Zoo-wide composting would divert food waste, animal droppings, and more from landfills
- Opportunity for patron education
- Implement signage to teach visitors about proper composting, its environmental benefits, and ease of application at home

Figure 13: Pathway leading up to Swan Lake and the Forest Preserve Nature Trail

Figure 14: Team members Max and Camryn working with sponsor John to modify current filtering system

Team SLR^3

Acknowledgements

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