

**To:** Mark Fisher and Jeff Koehn

**Cc:** Dr. Drew McAvoy

**From:** Sydney Cleverly, Jase Headings, Connor O'Keefe, Joel Steimle, Kate Shaughnessy

**RE:** Stormwater Reuse at the Cincinnati Zoo and Botanical Garden

**Date:** April 14th, 2023

Dear Mr. Fisher,

Fritz Consulting is pleased to submit the following final report for the Storm Water Reuse at the Cincinnati Zoo and Botanical Garden

Attached is the design proposal which includes:

- Literature review of collection options, storage options, treatment options, and runoff calculations
- Alternative analysis for collection options
- Alternative analysis for storage options
- Alternative analysis for pretreatment and primary treatment options
- Tables comparing all options against each other
- Recommendations for pretreatment, storage and treatment options

Fritz Consulting is excited for the opportunity to offer design services for the completion of this design proposal. We are available to answer questions and provide further information if needed, and thank you in advance for your consideration of Fritz Consulting.

Respectfully Submitted,

Sydney Cleverly

Jase Headings

Connor O'Keefe

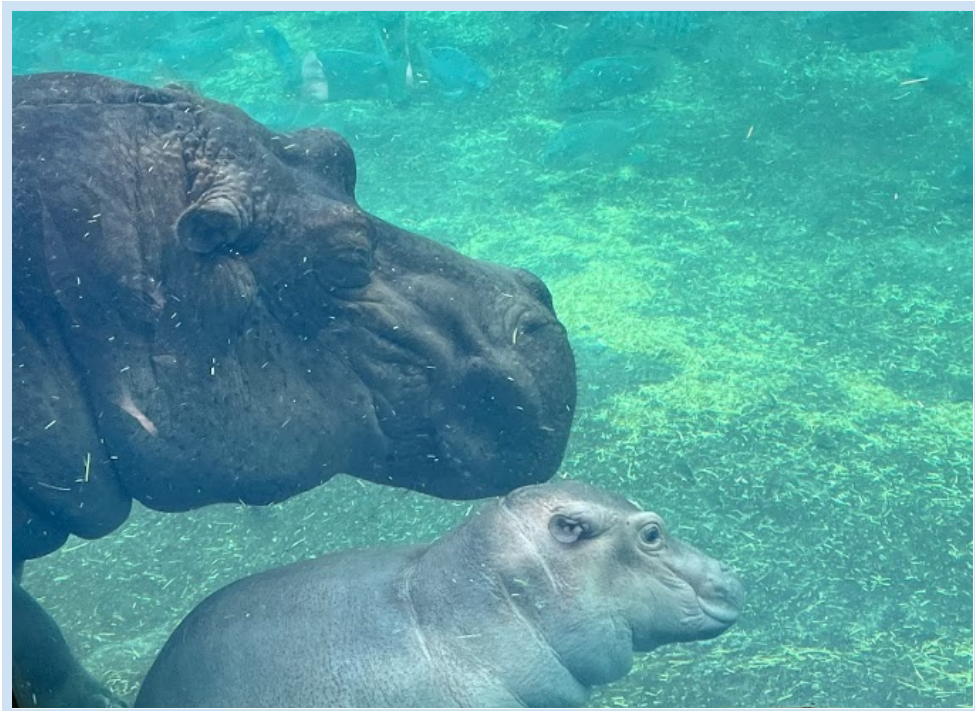
Joel Steimle

Kate Shaughnessy

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# Storm Water Reuse at the Cincinnati Zoo and Botanical Garden

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**Fritz Consulting**  
**F♦C**

Joel Steimle, Kate Shaughnessy, Jase Headings,  
Connor O'Keefe, and Sydney Cleverly

## Executive Summary

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Fritz Consulting was assigned by the Cincinnati Zoo and Botanical Garden (CZBG) to work with IBI Group to help the zoo achieve their goal of having “net zero” water usage by 2025. Fritz Consulting focussed on the Jungle Trails area of the zoo. We conducted a thorough review of the existing CZBG storm water reuse systems, as well as evaluated technology options for stormwater capture, storage, pre-treatment, and primary treatment. Each of these technologies was evaluated through alternative analysis using criteria of cost, maintenance, modularity, and treatment levels. The technology options considered were ranked with respect to each criteria, and assigned a weight for each criteria between 1 and 10 to represent importance.

Fritz Consulting reviewed site topography data and plans provided by IBI Group in Civil 3D to identify high slope areas, delineate pervious and impervious surface types, and calculate a subsequent runoff coefficient. Rainfall intensity data from MSDGC and IBI Group as well as site characteristics from Civil 3D data were used to calculate a total runoff flow rate of 1.3 MGD for a 25-year storm intensity in the Jungle Trails watershed. To accommodate for the unique site topography and land use, as well as the high runoff rate, Fritz Consulting recommends using french drains to capture stormwater in the Jungle Trails watershed. We recommend sending all captured raw water to an intermediate storage tank with pumps at the lowest point in the watershed, and recommend a precast concrete tank for storage. We recommend treating the raw water before storing it using sediment filter bags and hydrodynamic separators, and pumping the raw water to the oversized storage pipes in Elephant Trek to be stored and treated. To turn the raw water into clean water, we recommend utilizing the current treatment train CZBG has implemented throughout the campus, and using sand filtration, UV systems, and chlorination for primary treatment of the stormwater stored in Elephant Trek.

Fritz Consulting developed conceptual designs of the recommended system. We identified the locations for capture, treatment, and storage technologies, conducted an economic analysis of the recommended storm water reuse system, and outlined the separation of storm and sanitary sewer lines.

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## Introduction

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### 1.1 Scope

The Cincinnati Zoo and Botanical Garden (CZBG) set a goal to have “net zero” water usage by 2025. In the last ten years, through new capital projects, conservation, and maintenance, CZBG has reduced their water usage from roughly 300 million gallons per year to less than 50 million gallons per year. The Zoo previously implemented stormwater capture, treatment, and reuse systems in the Roo Valley and Africa exhibits, and is currently in the construction phase of their Elephant Trek project. The next area of the Zoo that CZBG intends to develop a water reuse system is the Jungle Trails exhibit.

### 1.2 Background

The Zoo is located in a combined sewer overflow (CSO) drainage shed. When major storm events occur, the combined sewers back up into basements of the surrounding neighborhood’s homes. This is a major public health issue for the community surrounding the Zoo, and CZBG wants to find a way to collect stormwater to use for toilet flushing, habitat and holding spray down, moats, and irrigation. By investing in rain water collection, treatment, and storage systems, the Zoo has the ability to reduce sewer back up for the local community, and reduce costs of domestic water use. The Jungle Trails exhibit has a large coverage of pervious areas, with many mature trees and steep slopes throughout the watershed. The Zoo wants to avoid cutting down trees for the construction of the water reuse system.

### 1.3 Approach

Fritz Consulting is working with CZBG and IBI Group to develop a plan to capture, store, and treat stormwater in the Jungle Trails Watershed area. Technologies were researched for capture, storage, pre-treatment, and primary treatment methods. Stormwater runoff was estimated using site plans and data from the city. This information, along with references from the previous water reuse projects at CZBG, were further used to assess researched technologies.

## Overview of Technologies

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### 2.1 Capture Technologies

The CZBG utilizes several different collection technologies, inside and outside of enclosures. The benefit of the previous developed spaces is the flat open landscape, making stormwater collection technologies easy to incorporate. Previous collection technologies are not suitable for this new project area because there is a sloped landscape with limited space in between existing structures. To help work towards the Zoo's net-zero goal, four collection technologies have been reviewed for the project area; bioswales, tree wells, bioretention area, and a catch basin with adjoined french drains. For each alternative collection technology, a small pump and/or pipe connection will be needed to transport the collected stormwater to the pre-treatment area.

#### 2.1.1 Bioswales

Bioswales are designed for the capture and control of stormwater runoff. The design is that of a constructed channel, or channels, lined and filled with appropriate vegetation to help prevent erosion and aid in infiltration of stormwater back towards the ground water table. Design considerations include runoff amount, capacity, and cross section shape of the channel. Channels can be natural or constructed, depending on the area's topography. Stable outlets need to be established as well to prevent ponding. As area increases, check dams are recommended to maintain channel stability and decrease stormwater runoff velocity. Different combinations of soiled base layers and vegetation are also possible designs. Scheduled maintenance is recommended for this technology, to inspect overall stability of the channel and materials replacement, if required.



*Figure 1: Bioswale Cross-Section (Source: Vegetated Swales, 2022)*

### 2.1.2 Tree Well

Tree well technology is designed to capture stormwater runoff, either collecting and redirecting to a re-use system, or to help areas with impervious pavements recharge groundwater. The species of tree depends on the local environment, but it needs to be able to handle long periods of dry or wet environments. The tree is placed towards the center of the target area; tree size affects how much space is needed. The pit which the tree will sit in has a gravel bottom for irrigation/infiltration. At this level a drain can be placed to capture and transport stormwater that has passed through the roots and soil substrate of the area. The next layer should be a soil substrate that best suits the needs of the root system. The surface level can be gravel, mulch, or grates depending on the site's needs. Surface level maintenance to prevent blockage around the tree should be done on an as-needed basis.

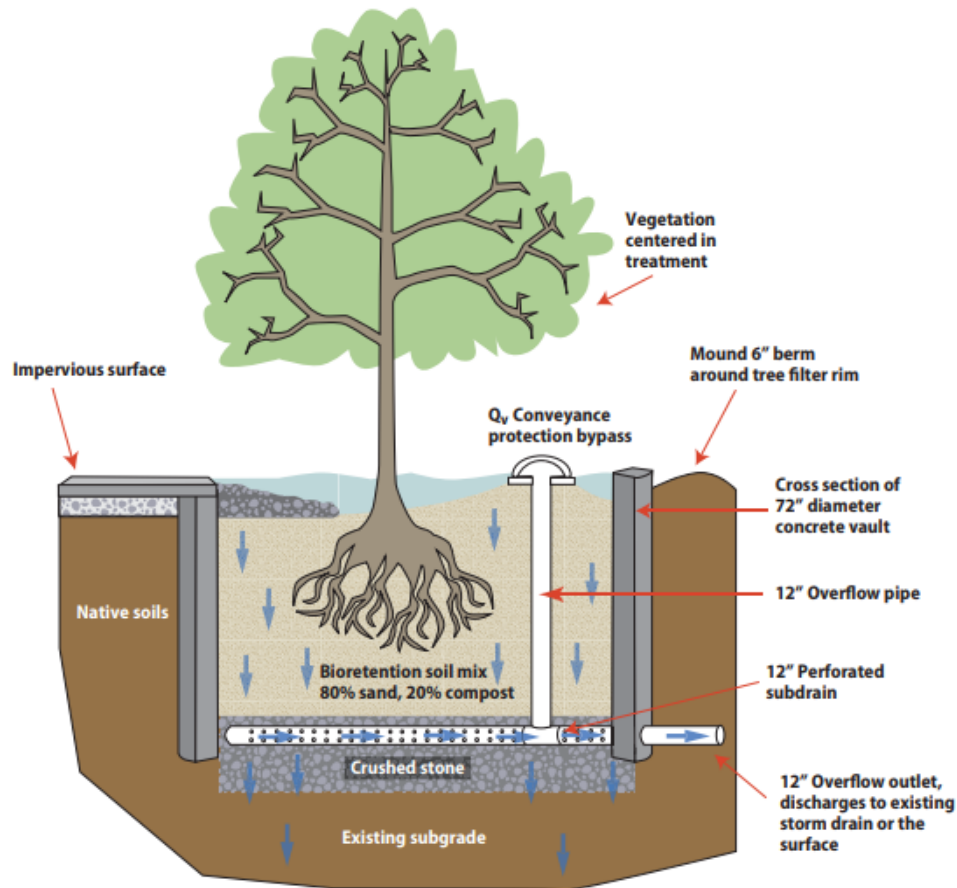


Figure 2: Tree Well Cross-Section (Source: Rutgers, 2013)

### 2.1.3 Rain Garden/Bioretention Area

A rain garden is a depressed area filled with vegetation that has infiltrating root systems. When a rain garden has a more complex design involving a drainage system, it is often referred to as bioretention. Bioretention areas can be designed to be ‘off-line’ or ‘on-line’ components. When being designed for stormwater management systems, they should be “on-line”. As part of the “on-line” system, an overflow outlet should be included, with space from the inlet location. The overflow outlet is often a type of stone weir. The inlet can be grasses, vegetated, or stone-lined narrow swale. The depressed area is filled with a gravel, pea-stone separator layer, and bioretention soil mix. A heavy wood mulch layer is lined across the top amongst the vegetation. The underdrain should be placed above the gravel layer, below the bioretention soil layer. If site location is prone to erosion, or unstable, a geotextile lining on the edges is recommended.

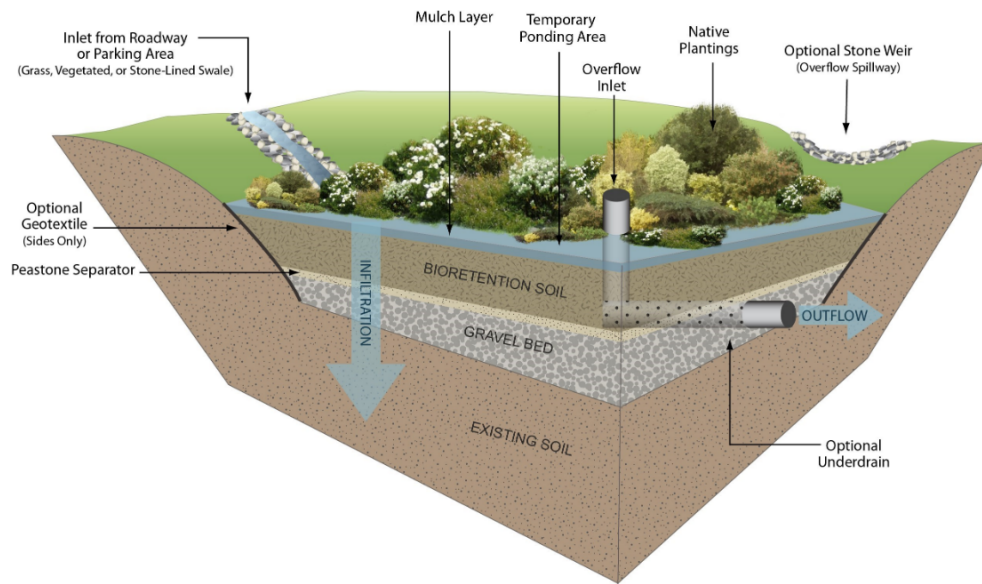


Figure 3: Cross- Section View for a Bioretention Area (Source: “Bioretention Areas & Rain Gardens.”, 2022)

#### 2.1.4 Catch Basin with French Drain

A catch basin is a plastic or concrete box with a fitted metal grate over top. French drains are a trench drain with a perforated pipe installed in the middle/low point. Stormwater can enter the pipe at any point and run downhill towards the outlet. The pipe size can be determined based on allowable space. Landscape fabric should be installed along the sloped trench to help protect the drain and provide stability. An outlet for the french drain can feed directly into a catch basin. When designing the drainage capture system combining these two technologies, multiple catch basins can be installed intermittently where the french drain is broken into segments, where the higher up drain is the inlet, and the lower being the outlet for the basin. Maintenance needs for such design should be observed and handled as necessary. This includes sediment removal, trench erosion control, and drainage pipe leaks/breaks inspection.

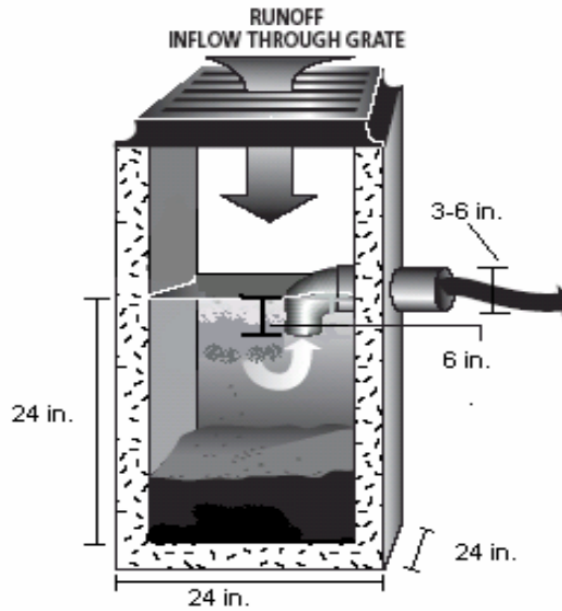


Figure 4: Standard Catch Basin Cross-Section View (Source: Portland Harbor: Catch basins, 2017)

### 2.1.5. Separation of Combined Stormwater and Sanitary Line

There are a number of pre-existing combined storm and sanitary sewer lines within the Jungle Trails watershed area. CZBG will be separating the current combined sewer lines into a set of parallel pipes, separating stormwater and sanitary water flow. This design choice will be done to direct stormwater capture for reuse on site. Fritz Consulting will provide an analysis of the current combined sewer separation and logistics during Phase II of the project.

## 2.2 Storage Technologies

The current vision of CZBG for storage within the Jungle Trails watershed is to utilize the low point within the watershed (and the entire zoo), located along Forest Avenue. This location would allow for any collected stormwater within the watershed to flow by gravity to the proposed storage location. However, this site also includes some physical constraints. The surrounding area is heavily wooded, and CZBG aims to preserve as many trees as possible during the construction process. Furthermore, there are many existing buried utilities present. It would be preferable to avoid these utilities and leave them undisturbed.

Given these constraints, CZBG and IBI have identified an excellent potential storage location beneath the existing 2,500 square foot Goetz Animal Health Center (Figure 5). The space beneath this structure, which is set to be demolished, would serve as both storage and a location for pumping via forcemain to the Elephant Trek water storage tanks.



*Figure 5: Goetz Animal Health Center location along Forest Avenue*

### 2.2.1 Steel-Reinforced Polyethylene Pipe

Steel-reinforced polyethylene pipe (SRPE) is a polyethylene pipe technology that is supported by steel reinforcing ribs. SRPE provides the lightweight, low cost, and durability benefits that characterize polyethylene. However, the steel reinforcing ribs also provide structural strength, resistance to temperature fluctuations and sunlight, and improved watertightness. SRPE can typically be manufactured in sizes up to 120" in diameter, providing a high volume of storage. Storage can either occur in one long run of pipe or multiple smaller runs to provide enhanced modularity. When compared to alternative pipe materials and other stormwater retention options, SRPE is lightweight and easily installed. This may reduce the

manpower and heavy machinery necessary during the installation process. Large diameter piping, such as 108" or 120", will allow sufficient space for regular pipe maintenance.

### 2.2.2 Precast Concrete Underground Tank

A precast concrete underground storage tank presents the advantage of reduced onsite construction activity. Such a tank could be purchased and constructed to fit the dimensions of the site. Precast concrete tanks can provide excellent durability and strength in excess of 5,000 psi, thus creating an impervious environment and eliminating the need for lining, coating, or sealing. They also have the advantage of maximizing storage within the space they fill.

### 2.2.3 Precast Concrete Modular Cistern

A precast concrete modular cistern storage tank is created by combining individual precast concrete modules into a large system capable of storing thousands of gallons of water (Figure 6). The modular design incorporates lateral and longitudinal passageways between modules to accommodate internal stormwater conveyance throughout the system. The inside dimensions of each module are 15 feet in length by 7 feet in width, with a customizable height between 2 and 14 feet. A modular cistern system allows for customization that can fit the constraints of a given site. These systems are designed to be accessible for maintenance, can withstand HS-20 traffic loading, and are able to maximize storage volume with minimum footprint. The modular nature of this technology allows for simple and quick installation. When designed for stormwater reuse, an impermeable geomembrane liner is installed around the modules to prevent water seepage.

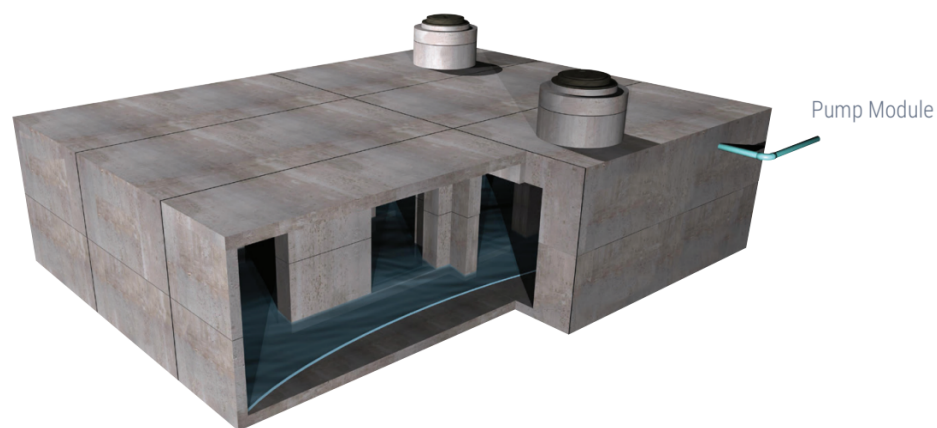
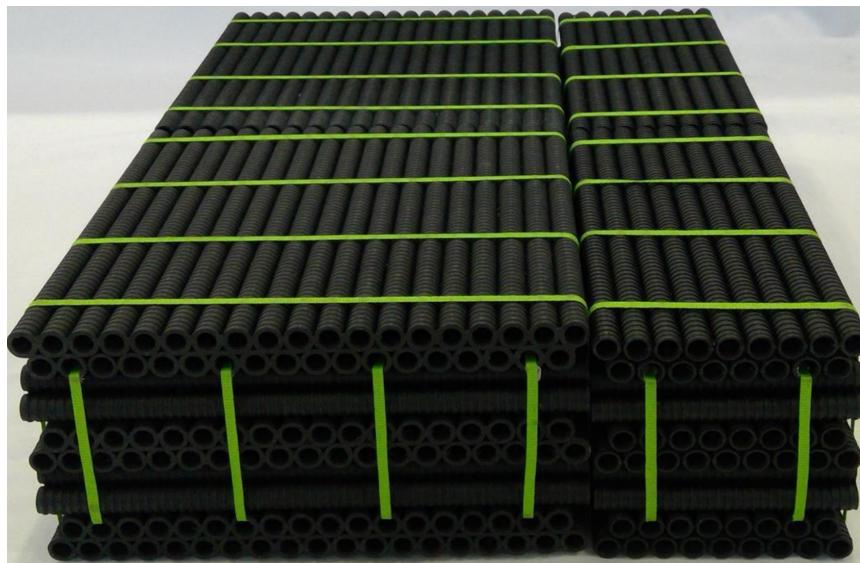


Figure 6: Precast Concrete Modular Cistern (Source: Oldcastle Infrastructure, 2022)

## 2.2.4 Bundled-Pipe Unit Reservoir System

Bundled-pipe unit reservoir systems are another form of subsurface water storage (Figure 7). The system consists of bundled-pipe units (BPU) of five HDPE pipes arranged in a two-over-three pattern and bonded into a single unit using polyethylene tie-strips. These BPUs create horizontal pre-compression stresses that increase the capability of resisting greater vertical loading with minimal deflection when compared to a single pipe. These BPUs can be combined and stacked to create a highly customizable storage system that fits the constraints of the site. This technology offers a very high storage capacity, equivalent to 96% voids of the total occupied volume of the reservoir. The system is wrapped in a geotextile envelope to prevent soil migration into the system and water loss to the soil, when used for stormwater reuse. Stormwater runoff can be channeled into the system either through conveyance pipes or direct seepage through the overlying material. The system can be customized to contain both an emergency overflow pipe and outflow pipe, which can be linked to one or multiple pumps. In order to ensure consistent and adequate performance of the BPU system, regular maintenance would need to be performed. Maintenance would include installation of an upstream pretreatment system to remove sediment and periodic flushing and vacuum pumping to remove buildup of solids.



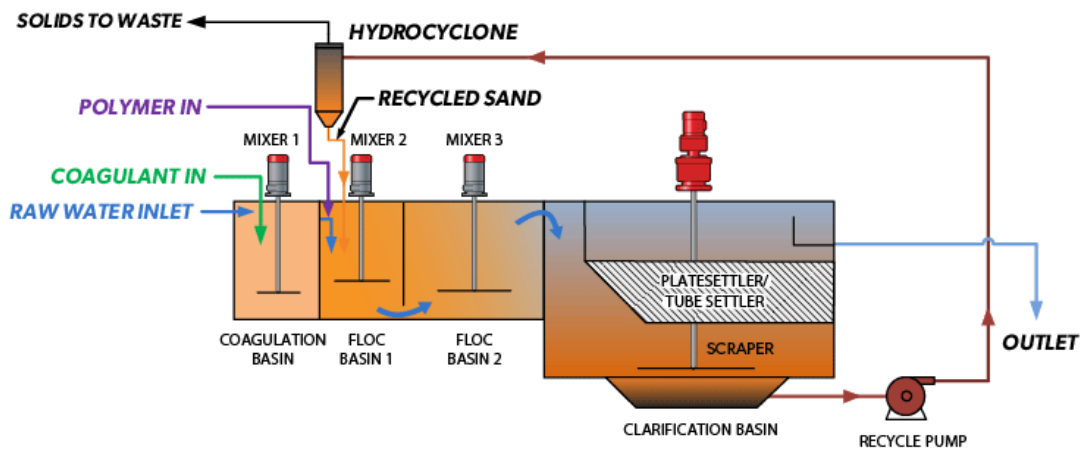
*Figure 7: Bundled-pipe unit chamber configuration (Source: Environmental Conservation Solutions)*

## 2.3 Pre-Treatment Technologies

Pretreatment is the first step in the treatment of stormwater for the purpose of reuse. Four technologies have been identified and described below, including ballasted flocculation, hydrodynamic separation, sediment filter bag, and bioswale.

### 2.3.1 Ballasted Flocculation

Ballasted flocculation uses a chemical polymer to assist with flocculation, a physical-chemical process in which suspended solids form large clusters and are removed from the water (Figure 8). Chemicals such as ferric chloride or alum are added to help solids bind onto the ballast (typically sand). Ballasted flocculation features high TSS and BOD removal and can operate at a variety of flow rates. A large footprint is required for ballasted flocculation and it has more complex instrumentation and controls compared to other pretreatment technologies.

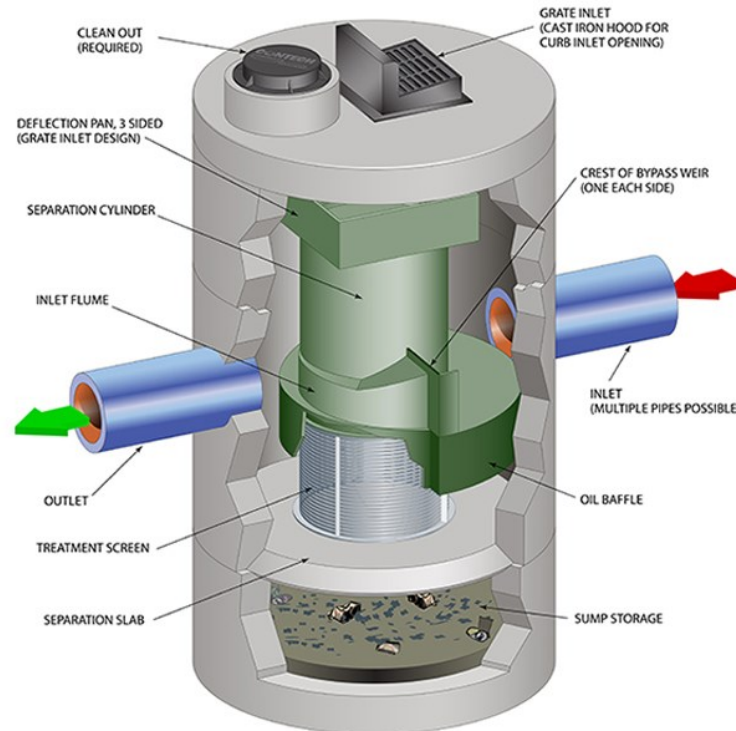


*Figure 8: Ballasted flocculation process diagram.  
(Source: WesTech RapiSand Ballasted Flocculation)*

### 2.3.2 Hydrodynamic Separator

Hydrodynamic separators use a high velocity vortex motion within a cylindrical chamber to remove particles of varying densities (Figure 9). As raw stormwater flows through the hydrodynamic separator, the swirling motion causes large particles to settle in a separate

chamber and floatables to be captured at the top. Hydrodynamic separation is effective in removing sediment, trash, debris, and hydrocarbons and does not require a large footprint. An advantage of hydrodynamic separators is that they can be used in combination with other capture or pretreatment methods, especially to provide additional treatment capacity during high flow rate storm events.



*Figure 9: Hydrodynamic separator diagram.  
(Source: S3 Stormwater Solutions Source, Hydrodynamic Separators)*

### 2.3.3 Sediment Filter Bag

Sediment filter bags are a simple stormwater protection technology that collects and removes large particles from stormwater runoff. Sediment bags are a commonly used pretreatment method and are very popular at construction sites where they are used to capture and remove sediment from water with high turbidity. At the point of collection, raw stormwater runoff passes through a filter bag before it enters the stormwater piping system. Sediment bags are effective in removing large particles such as sediment, organic debris, and street trash and

can easily be added to a stormwater treatment train as the first line of pretreatment. Maintenance is simple but must be completed on a regular basis to ensure the bags are not clogged. If the bag becomes full, stormwater can no longer flow at a reasonable rate which can either cause flooding or clog treatment technologies downstream if an overflow bypass is used.

#### 2.3.4 Bioswale

Bioswales are channels lined with vegetation that collects and filters stormwater. Bioswales are a type of Low Impact Development (LID) or Green Infrastructure (GI) that attempts to mimic a site's natural hydrological function to manage stormwater runoff. This makes them a visually pleasing alternative despite requiring a large footprint area. Bioswales use vegetation, soil, filter media, and an underdrain to pre-treat and capture stormwater runoff for reuse. Impermeable liners and check dams can also be used to reduce flow velocity and increase capture. Bioswales are effective in removing street trash items, organic debris, and suspended solids. Maintenance is required to remove accumulated trash and debris and to maintain vegetation health.

### 2.4 Primary Treatment Technologies

Many treatment technologies are used at the Zoo for stormwater reuse. These include sand filtration, chlorination, ultraviolet, and ozonation. Current and existing technologies have been identified and described below, including rapid sand filtration, microfiltration, cellulose-based filtration, ultraviolet, and chlorination.

#### 2.4.1 Rapid Sand Filtration

Sand filtration is a tried and true water treatment technology for stormwater reuse (Figure 10). It is typically placed near the beginning of the primary treatment process as it targets turbidity reduction by removing solids, heavy metals, and microorganisms through biological and physical processes. This is accomplished by fine sand filter media residing in tanks ranging from a few cubic feet to several hundred cubic feet in volume. After excessive use, sand filters must be backwashed manually or remotely to clean the sand filter media and return removal performance to near or equal to its original state.

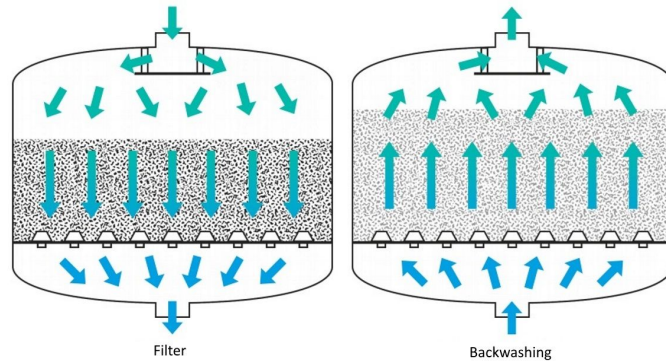


Figure 10. Rapid sand filtration diagram. (Source: Reijnen, 2020)

### 2.4.2 Microfiltration

Microfiltration (MF) is a less common technology used for water treatment (Figure 11). The MF process utilizes gravity or pressure to force water through manufactured, micro-porous membranes. MF targets particulates and bacteria, and has also proven to remove some macromolecules and viruses. MF membranes typically consist of high-performance plastics wound in spiral configurations to increase durability and performance. Common polymers used to manufacture the filters include polyimide and polysulfone. Like sand filtration, backflushing is required to clean trapped solids and microbes from the filters to return filtration performance to its original state. Aeration is also found to be an alternative to backflushing. Air is introduced to the filter membrane via injectors and helps recover the flow rate and performance of the filter membrane.

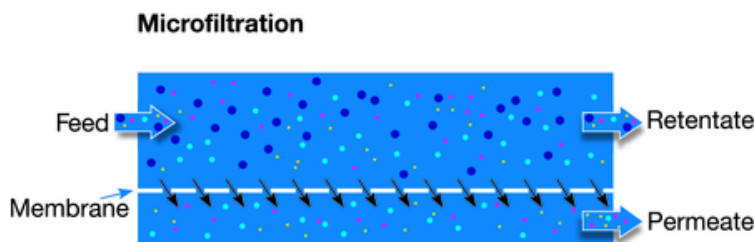


Figure 11. Microfiltration diagram. (Source: What is membrane filtration?, 2022)

### 2.4.3 Cellulose-Based Filtration

Cellulose-based filtration is a treatment technology widely studied for heavy metal and organic pollutant removal (Figure 12). Cellulose-based filtration material comes in many forms,

including gels, composites, and other derivatives. In addition to the mentioned modifications, additives and pretreatments are also known to increase adsorption capacity. Being natural and abundant, many forms of cellulose-based filtration are relatively inexpensive technologies and are considered a cleaner alternative to fossil fuel-based polymers. Filtration materials are commonly sourced from plants such as cottons, rice husks, banana rachis, and sugarcane bagasse. The presence of hydroxyl groups in the cellulose chains allow for crystalline, web-like structures to form a filter medium. While material availability is not an issue, regeneration of media is limited to less than a dozen cycles for most forms, so media disposal must be considered. Flow rate is another limitation for this form of filtration.

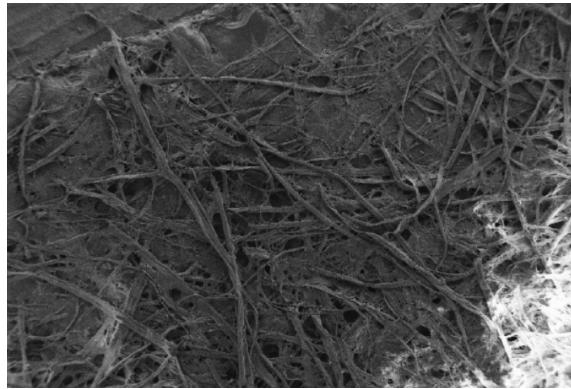


Figure 12. SEM micrograph of cellulose fibers. (Source: Bodîrlău et al., 2013)

#### 2.4.4 Ultraviolet

Ultraviolet (UV) treatment is another commonly used water treatment technology for disinfection (Figure 13). Utilizing replaceable mercury vapor lamps within quartz sleeves, UV light is delivered to water as it flows through the main reactor. Effective UV treatment relies on water with high UV transmittance (UVT) upon entering the reactor. This ensures the UV dose delivered to the passing water is maximized and microbes are inactivated; ultimately, this process de-activates microbe replication. UVT technology typically resides as the final treatment step before use. UV is also known to inactivate microbes resistant to other forms of disinfection, so system performance is maximized when paired with treatment technologies such as chlorination and ozonation.

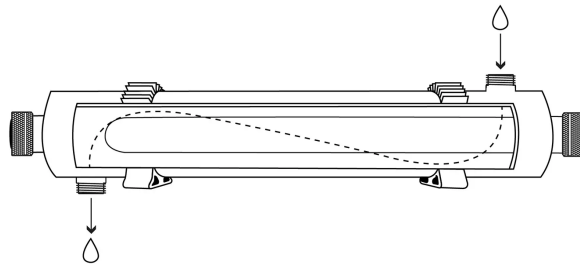


Figure 13. Conventional UV reactor diagram. (Source: *What Is Ultraviolet Water Treatment?*, 2022)

#### 2.4.5 Chlorination

Chlorination is another treatment technology used for disinfection purposes (Figure 14). Targeting pathogens, it is an indispensable process used to improve the hygienic quality of water reuse treatment systems. Chlorine is introduced to water via solution injection or tablet addition. Chlorination is an effective disinfection technology due to the strong oxidative power of free chlorine, which is generated by the reaction of chlorine gas in water. Automated chlorine systems require monitoring to ensure measured levels are accurate and feed rates do not exceed safe levels. An unavoidable problem with chlorination is the resistant parasitic species and bacterial strains. Due to this, other treatment technologies are often paired with chlorination to ensure proper disinfection is achieved.



Figure 14. Chlorine injection system. (Source: *Stenner Single Head Proportional Chemical Injection System*, 2020)

## Preliminary Stormwater Analysis

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The nature of the Jungle Trails watershed is unlike any other watershed at the zoo, as it has a highly sloped terrain with a high percentage of pervious area. To aid in the alternative analysis process and recommendation decision, a preliminary analysis was performed to analyze the grading of the watershed and the surface types. This data, along with rainfall intensity data provided by MSD and IBI Group was used to calculate the runoff that would be generated from the watershed.

### 3.1 Surface Runoff and Collection

The current CAD file for the entire Zoo campus provided by IBI was used to find the runoff coefficient for the watershed. IBI also provided an excel calculator that defined three land uses for the site: open spaces, impervious areas, and steep hillsides. The master drawing of the jungle trails watershed was delineated into three areas to represent each land use, and the area of each was calculated in Civil 3D. To distinguish the steep sloped hillsides from general open spaces, a topographic map of the Zoo was utilized to generate a data visualization of the steep sloped areas of the site using Civil 3D (Figure 14). As a result, a weighted runoff coefficient was calculated for each land use area, and a runoff coefficient of 0.55 for the entire Jungle Trails watershed was found (Table 1).

*Table 1: Jungle Trails Land Use Distribution With Roof Area Included*

Land Use	Runoff Coefficient	Area (sq ft)	Weighted Coefficient
Open Space (meadows, grass, woods, lawns, etc.)	0.3	142,728	0.07
Impervious Areas (parking lots, roads, roof tops)	0.9	145,174	0.21
Steep Wooded Hillside (Slope >10%)	0.5	333,032	0.27
<b>Total:</b>			<b>0.55</b>



*Figure 15: CZBG Site Layout with Steep Slope*

### 3.2 Rainfall Analysis and Runoff Calculation

The Rational Method (See Rational Method in the appendices) was used to calculate the total runoff volume for the site. The data for the calculation included the previously calculated runoff coefficient, the total site area provided by IBI, and rainfall intensity data provided by both IBI and the Metropolitan Sewer District of Cincinnati (MSDGC). Rainfall intensity data from MSDGC was provided for time of concentration values between 10 minutes and 60 minutes. Fritz Consulting considered using the TR-55 method to calculate the time of concentration for

the watershed, but after consulting with IBI, a time of concentration of 10 minutes was selected to be as conservative as possible, since it would generate the highest possible rainfall intensity (Table 2).

*Table 2: Rainfall Intensity Level Data (Source: IBI Group and MSDGC)*

	<b>Rainfall Intensity for 24 Hour Storm (in/day)</b>			
<b>Tc (min)</b>	<b>2 year</b>	<b>10 year</b>	<b>25 year</b>	<b>100 year</b>
10.0	4.08	5.45	6.30	7.69

In order to calculate a runoff flow rate, the 24-hr, 25-year storm was used. As a result, a runoff flow rate of 1.3 million gallons per day over the entire Jungle Trails watershed was found. (See example calculation in the appendices).

## Alternative Analysis

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For each alternative analysis matrix, every option was evaluated on a weighting scale of 1-10, based on the importance of that criterion, with 10 being most important, and 1 being least important. To calculate a weighted score, the alternative rating was multiplied by the weight for that specific criterion. The sum of the scores was taken to calculate the final weighted score, and the alternative with the highest score represents the best alternative.

### 4.1 Capture Technologies

The capture technologies were evaluated by looking at 5 criteria; size, maintenance, cost, effectiveness, and modularity. The CZBG has limited space and changes in elevation throughout the property. These obstacles make it difficult to apply typical capture systems that are designed for flat/ low-slope elevations. For this reason, size of capture technology was most important. The second criteria to be considered was each technology's maintenance needs. From designs in the past to the overall area of the CZBG maintenance needs should be simple and easily accessible. Cost of each technology was evaluated as well. CZBG is an organization that in the past has spent the money required to achieve a design that holds up to the needs of the Zoo. Effectiveness of each capture technology is important to work towards the Zoo's goal of a Net Zero\* system, where they will capture as much storm water as capable on their property to treat and use. The final criteria looked at for each technology was modularity. In this case modularity refers to the capability of each technology to be modified or changed in the area. CZBG has been under constant progressive change for nearly twenty years. Some of that change has been correcting or changing old designs. Separation of storm and sanitary sewer lines was not analyzed in the alternative analysis process, since the lines will be separated. The logistics of the separation and any new pipe locations will be outlined in the spring of 2023.

#### 4.1.1 Bioswale

Bioswales are a commonly used technology for stormwater management because of their visual appeal and capture capabilities. The size of a bioswale makes them efficient for varying stormwater runoff amounts. The additional sub layers make it easier for bioswales to

store and hold more water for a longer period of time after the rain event. However, bioswales have to be cleaned continuously as they are an easy collection point for trash and other debris that gets collected in stormwater runoff. Maintenance is important to not only remove the trash and debris, but to help maintain the vegetation and drainage points if the bioswale has them. If not maintained properly several issues can occur, such as flooding and standing water. The price to create a bioswale varies, but is relatively low. The highest contributor to price is gravel and vegetation cost. Although bioswales are not highly modular, if designed properly they do have a lifespan of 20-50 years, depending on stormwater intensity over the years.

#### 4.1.2 Tree Well

Tree wells are typically seen in areas with a high impervious surface area. Similar to other stormwater management designs, the tree wells act as a collection point for the stormwater runoff. The benefit of a tree well is they are adjustable to size. Different size trees can be chosen for the design to still work. The location for the tree well would need to be at the bottom of the sloped area to help direct the runoff. Although this area is not surrounded by impervious surfaces, the sloped land increases the speed of the runoff, leading to a lower amount of infiltration. Depending on certain design features, such as the tree root system and soil composition, a tree well can hold roughly six to eight inches of stormwater runoff. Beneath the surface, the tree roots sit in a soil substrate on top of a gravel bedded layer where a drainage pipe can be placed. The problem with this design is the drainage pipe would require a small pump to move the collected stormwater to the pre-treatment area. Maintenance would need to be done at a bare minimum of monthly routines and after large storm events. Clearing debris and trash to prevent blockage is a priority. However, for the subsurface pipe and pump, maintenance access would be very limited.

#### 4.1.3 Rain Garden/ Bioretention Area

Rain gardens are depressed areas of land, often planted with grasses and perennials, for stormwater runoff to flow into. A bioretention area is a rain garden with a drainage system and amended soil. Similarly, size is the main contributing factor. Rain gardens have a higher collection efficiency as the size increases. Gravel or constructed channels can be implemented

to help conduct the runoff towards the depressed area. Space permitting, a stone weir may be necessary toward the opposite side of the main inlet point. Rain gardens have a higher price point as well due to the different varieties of materials used in design, such as different gravel, soil, and vegetation types. Vegetation for rain gardens is more advanced than just grass, typically containing more perennial type plants. A mulch layer is preferred to be added with the selected vegetation in case ponding occurs. Maintenance to keep the area clean and ensure there are no blockages should be done regularly on a bi-weekly schedule in the first year until the vegetation is more mature.

#### 4.1.4 Catch Basin with French Drain

Catch basins are often used in grassed areas where ponding occurs to help drainage. However, for the CZBG they will be used to collect stormwater runoff that would otherwise go into the combined sewer system. Different sizes are offered in the pre-cast options for catch basins, making it easier to adapt to size limitations of the Jungle Trails area. The purchase cost can vary depending on the size of the catch basin installed. Maintenance should be regular, however it is typically only needed after storm events to clear the grate of any debris or other blockages. A french drain is used in similar areas, sometimes where there is a space limitation or aboveground obstacles. French drains and catch basins are often coupled together to help direct the stormwater into the catch basin during and after storm events. Having elevation helps transport the stormwater through the drain, otherwise stormwater can get caught and sit in the drain causing several problems. For the site location in Jungle Trails, the sloped area is a benefit to this design rather than a complication like the other alternatives. The size, maintenance needs, and compatibility with sloped landscapes makes catch basins and french drains excellent for the stormwater runoff capture for the Jungle Trails area.

#### 4.1.5 Separation of Combined Stormwater and Sanitary Line

The separation of the existing stormwater and sanitary line was not included in the alternative analysis because the CZBG had already confirmed that they will be implementing the separated lines.

Table 3: Comparative Analysis for Capture Technologies

Comparative Analysis Data for Capture Technologies				
Alternative	Bioswale	Tree Well	Rain Garden/ Bioretention Area	Catch Basin w/ French Drain
<b>Total Cost</b>	\$0.85-\$2.30/cf	N/A	\$5-\$30/sq ft.	\$150-\$500 + \$20-\$30/ft
<b>Modularity</b>	Low	Low	Low	High
<b>Footprint(sq ft.)</b>	~21,000	N/A	~10,000	30 cf(3'x2'x5') - Catch Basin ~0.5 ft X Length drain(subsurface)
<b>Maintenance</b>	Annual/As- Needed	Monthly	Bi-weekly	Monthly
<b>Collection Amount</b>	1 ft/s*	0.42ft/hr**	<5 ft <sup>3</sup> /s	Dependent on slope

\*Based off 10 yr rain event \*\*refers to surface loading

Table 4: Alternative Analysis for Capture Technologies

Capture Alternative Analysis					
Criteria	Weight	Bioswale	Tree Well	Rain Garden/ Bioretention Area	Catch Basin w/ French Drain
<b>Size</b>	10	1(10)	3(30)	2(20)	4(40)
<b>Maintenance</b>	8	4(32)	2(16)	1(8)	3(24)
<b>Cost</b>	5	1(5)	3(15)	2(10)	4(20)
<b>Effectiveness</b>	2	2(4)	1(2)	3(6)	4(8)
<b>Modularity</b>	1	1(1)	2(1)	3(3)	4(4)
<b>Unweighted Score:</b>		9	11	11	19
<b>Weighted Score (Max 116)</b>		52	64	47	96

The CZBG has utilized bioswales, rain gardens, and catch basins throughout the property, and each of them has significant benefits. Bioswales and rain gardens work great for enclosures and open common areas, but their size requirements are not suitable for the design location, which is reflected in their analysis scores. Catch basins are simple and easy technologies that the CZBG has creatively placed along the walking paths and in enclosures. The catch basins provide an efficient collection point for stormwater to be captured and sent to the on-site treatment and storage facilities. However, around the CZBG, the paved walkways provide a guided path to different catch basins, where the difference in the Jungle Trials site is there will not be paved walkingways along the hill side. French drains are an alternative solution to help

guide the stormwater to the catch basin collection points. Catch basins also have the benefit of small size, lower cost, easy maintenance, and if needed in the future they have a very modular set-up.

## 4.2 Pre-Treatment Technologies

The five criteria chosen to evaluate pretreatment alternative options were treatment level, overall cost, technology footprint, and ease of use. Note that these criteria are being weighted on a 10-point scale to adequately represent the importance of each and to offer sufficient diversity in the data for choosing the best technology. Due to the primary objective of reusing the stormwater that is captured, treatment level was determined to be the most important criteria in determining the best pretreatment technology. The treatment level can be broken into two categories for pretreatment including fecal coliform and TSS removal efficiencies. Of these two categories, TSS removal is given a higher importance due to the primary treatment technologies being used downstream in the treatment train. Maintenance has also been a major issue and area of concern for the Zoo and was given the next highest weighting for importance. Next of importance was total costs for each technology including material and installation costs. The total cost includes estimates for material and installation costs. Available space in the Jungle Trails project area is limited and includes many obstacles both above and below ground, making technology footprint an important factor to consider. Lastly, ease of use is being evaluated. The technologies within this criterion are ranked by simplicity and the Zoo's familiarity with each. This helps determine if there are any feasibility issues or large operational challenges associated with each alternative.

### 4.2.1 Bioswale

Bioswales are a green infrastructure technology that is efficient in collecting and pretreating stormwater on site. The vegetation and soil acts as an effective filter media and can remove up to 70% of TSS and a small percentage of fecal coliforms. Initial costs are fairly high, but once the bioswale is installed maintenance is minimal. Maintenance is required at most once a month and each time after a greater than 2 inch storm event to remove trash and debris.

Bioswales are already being used at the Zoo as part of previous water reuse projects, however, the Jungle Trails area is limited in space and features steep terrain, making bioswales difficult to implement effectively.

#### 4.2.2 Ballasted Flocculation

Ballasted flocculation is a relatively new pretreatment technology in the United States and is typically found as part of larger scale wastewater treatment trains. It is effective in removing up to 85% of all TSS and around 70% removal of fecal coliforms (Table 5), making it the technology with the highest overall treatment capabilities. Ballasted flocculation requires specialized maintenance to ensure proper function. It is a relatively advanced pretreatment technology and requires a certain level of technical skill among employees working with it. Exact footprint and cost information are not available for ballasted flocculation at a small scale that would be required at the Zoo, however, based on estimates it would likely be the largest and most expensive of the pretreatment methods considered.

#### 4.2.3 Hydrodynamic Separator

Hydrodynamic separators are a cost-effective pretreatment method commonly used in stormwater management systems. They use gravity to settle large particles and phase separation to remove hydrocarbons and debris, achieving 80% TSS removal (Table 5). Hydrodynamic separators are fairly compact and are placed underground, making them a great option when space is limited. Depending on the volume and frequency of storm events, hydrodynamic separators only need to be inspected and cleaned once every 2-4 months and fully vacuumed out annually. They can be used inline or offline, allowing for easy overflow bypass that will be required during larger storm events. Hydrodynamic separators are already successfully used at the Zoo and the staff is familiar with proper operation and maintenance.

#### 4.2.4 Sediment Filter Bag

Sediment filter bags are a simple stormwater pretreatment technology that can attach to drainage inlets and serve as permanent protection against litter, debris, and other large particles. Up to 85% of all TSS can be removed by using filter bags (Table 5). These inserts can be

made of stainless steel and are easy to maintain, requiring regular inspection and clearing especially after large rain events. Sediment filter bags have low material and installation costs and have a small footprint, being the same size as the inlet itself. The simplicity and low cost make them a great first step in the treatment and reuse of stormwater.

#### 4.2.5 Sediment Filter Bag + Hydrodynamic Separator

Sediment filter bags are a simple technology that can easily be added to a stormwater reuse treatment system as a first line of protection against sediment and debris. When used in combination with a hydrodynamic separator, it is possible to increase the TSS removal efficiency up to 90% with only a minor increase in cost (Table 5). The addition of sediment filter bags can also slightly decrease the overall maintenance time and difficulty since the bags can be cleaned during regular inspections, limiting the amount that can build-up in the hydrodynamic separator. Both of these technologies are already being utilized by the Zoo, making an easy transition in use and maintenance.

#### 4.2.6 Comparative Analysis for Pretreatment Technologies

Available data covering costs, removal efficiencies, maintenance, and required footprints for the selected pretreatment technologies is compared in Table 5. Using this data, Table 6 contains the results of the alternative analysis conducted for these technologies.

*Table 5: Comparative Analysis for Pretreatment Technologies*

Comparative Data for Pretreatment Alternatives					
	Ballasted Flocculation	Bioswale	Sediment Bag	Hydrodynamic Separator	Sediment Bag+ Hydro
<b>Material Cost</b>	*Unavailable	\$11,000	\$500	\$9,000	\$9,500
<b>Total Cost</b>	*Unavailable	\$12,000	\$600	\$10,000	\$10,600
<b>Fecal Coliform Removal</b>	70%	<20%	0%	0%	0%
<b>*TSS removal</b>	85%	60-70 %	up to 85%	80%	>90%
<b>Maintenance hours per year</b>	60	15	4	12	8
<b>Total Footprint (sqft.)</b>	Largest footprint	200	~6 / bag	80	86
<b>Proven technology?</b>	No	Yes	Yes	Yes	Yes

Table 6: Alternative Analysis for Pretreatment Technologies

Pretreatment Alternative Analysis						
Criteria:	Weight:	Ballasted Flocculation	Bioswale	Hydrodynamic Separator	Sediment Bag	Sediment Bag filter + Hydro
Treatment Level	10	5 (50)	2 (20)	3 (30)	1 (10)	4 (40)
Maintenance	8	1 (8)	2 (16)	3 (24)	5 (40)	4 (32)
Cost	5	1 (5)	2 (10)	4 (20)	5 (25)	3 (15)
Footprint	3	1 (3)	2 (6)	4 (12)	5 (15)	3 (9)
Ease of Use	1	1 (1)	2 (2)	4 (4)	5 (5)	4 (4)
Unweighted Score		9	10	18	21	18
Weighted Score (out of 135)		67	54	90	95	100

While ballasted flocculation has the highest overall treatment performance, it is limited by its cost, required footprint, and complexity of operation. Bioswales perform average to poor across all decision criteria and are additionally challenging to implement due to the steep topography. Hydrodynamic separators had a high overall score despite only performing average in the two most important criteria, treatment level and maintenance. Sediment bags scored highly across nearly all decision criteria, however, it failed to meet the desired treatment level. It was found that a combination of sediment filter bags and hydrodynamic separator had the highest overall weighted score (Table 6). This combination of pretreatment technologies offers a high treatment level with minimal maintenance, low cost, relatively small footprint, and simple operation. These technologies are currently being used on the Zoo’s campus and do not require any additional training before use. It is for these reasons that a hydrodynamic separator and sediment bags were selected as the pretreatment technologies.

### 4.3 Storage Technologies

Five criteria were used to evaluate storage alternatives: site compatibility, maintenance requirements, storage capacity, longevity, and cost. The criteria chosen reflect the project objective of stormwater reuse, lessons learned from past CZBG projects, and the constraints associated with the site. The storage technology will be located in a relatively cramped area; there are many surrounding trees and utilities that need to be protected during the construction process. As a result, site compatibility was chosen as the criteria of highest importance. A storage alternative is desired that will maximize the provided space while

minimizing disturbance to CZBG's existing resources. Maintenance requirements, which include both frequency and ease of maintenance, were the second important consideration. CZBG is seeking to prevent the maintenance issues previously experienced within the storage system in the Africa exhibit, where the chamber system in place clogged frequently and maintenance access was limited. The third most important criteria was cost. Relative cost was assigned on a 1-5 scale, with 5 representing the highest expected cost. Lastly, storage capacity followed by longevity are being considered. CZBG desires a storage alternative that is durable, will have a long service life, and will maximize water storage volume given an equal footprint. The cost of the chosen alternative will be researched with more specificity during Phase II.

#### 4.3.1 Steel-Reinforced Polyethylene Pipe

Steel-reinforced polyethylene pipe, such as DuroMaxx pipe manufactured by Contech Engineering Solutions, offers excellent durability and longevity when compared to traditional HDPE pipe. DuroMaxx is estimated for a lifetime between 50-100 years, so a lifespan of 75 years was assumed. For use in storage tank applications, a large pipe diameter would likely be chosen, such as 120". A pipe size of 120" would also be large enough for a person to enter, making any needed maintenance or clearing much easier. Multiple pipes could be lined side by side to meet the storage capacity needs of the site. However, in order to install SRPE of that size, a relatively large construction footprint would be required. It would be quite difficult to meet the constraints of the Goetze Animal Health Center site without interfering with surrounding utilities or requiring tree removal. The cost of SRPE is also high when compared to other alternatives.

#### 4.3.2 Precast Concrete Underground Tank

The major advantage of the precast concrete tank alternative would be its compatibility with the physical constraints of the chosen site. A precast concrete tank could function as a "basement wet well" below the demolished Goetze Animal Health Center. The tank surface area could span the floor of the building and be excavated below grade to meet the tank storage requirements. A precast concrete tank could also house submersible water pumps used to convey water to the Elephant Trek tanks. Therefore, a precast concrete tank would help to avoid

utilities and tree removal, maximize storage capacity, and minimize footprint. Such a tank could be physically entered by staff as maintenance and repair needs arise. One disadvantage, however, is the lack of modularity associated with this alternative. If contaminants or excessive solids enter the tank, the entire tank would be exposed and the pumps could be damaged. This issue could be mitigated by effective pretreatment and or by installation of some filtration device within the tank, such as a faircloth skimmer above the pumps.

#### 4.3.3 Precast Concrete Modular Cistern

The precast concrete modular cistern alternative displays many of the same advantages as a precast concrete underground tank. The StormCapture system by Oldcastle Infrastructure was used as a reference product. This technology fits well with the site constraints. Due to its modular nature, the system could be customized to fit the space allotted below the existing Goetze Animal Health Center building without much wasted space. A modular cistern system has a high storage capacity to footprint ratio and would likely prevent disturbance in the surrounding area. These systems are typically equipped with maintenance modules that provide access to the system for ongoing inspection and maintenance. Twice-yearly inspection and maintenance is recommended to remove trash, debris, sediment buildup, and other contaminants. In regard to longevity of the system, this alternative is attractive due to the potential of replacing individual modules rather than the entire system.

#### 4.3.4 Bundled-Pipe Unit Reservoir System

The bundled-pipe unit reservoir system evaluated for the purpose of this alternative analysis was the PIPE-R Reservoir System by Environmental Conservation Solutions. A BPU reservoir system, due to its modularity and highly customizable nature, could fit within the site constraints very well. BPUs can be arranged into many different configurations to maximize storage in a highly variable space. Cost and storage capacity are highly competitive as well, though storage may not be as efficient as a precast concrete tank or precast concrete modules. The recommended minimum design life for a system constructed with HDPE pipe is 50 years. However, the major concern associated with BPU systems is maintenance. Unlike the other storage alternatives, physical access into the system would not be possible. To perform maintenance and remove sediment accumulation, inspection/maintenance ports are installed

within the body of the reservoir system and the inlet/outlet manifolds. To remove sediment, contaminants, and other buildup, the reservoir is flushed with water and then discharged using a vacuum truck. Once the system and surrounding area has been constructed, access by a vacuum truck may be difficult. Environmental Conservation Solutions recommends quarterly inspection for the first year and twice annual inspection thereafter.

#### 4.3.5 Alternative Analysis for Storage Technologies

The four technologies were ranked on a scale from 1-4, with 4 representing the highest relative score, for each chosen criterion. The score for each technology was multiplied by the weight assigned to each criterion to generate a total weighted score.

*Table 7: Alternative Analysis for Storage Technologies*

Storage Alternative Analysis					
Criteria	Weight	Steel-Reinforced Polyethylene Pipe	Precast Concrete Underground Tank	Precast Concrete Modular Cistern	BPU Reservoir System
Site Compatibility	5	1 (5)	4 (20)	3 (15)	2 (10)
Maintenance Requirements	4	3 (12)	3 (12)	4 (15)	2 (8)
Cost	3	1 (3)	3 (9)	2 (6)	4 (12)
Storage Capacity	2	2 (4)	4 (8)	4 (8)	3 (6)
Longevity	1	4 (4)	3 (3)	4 (4)	2 (2)
<b>Unweighted Score:</b>		11	17	17	13
<b>Weighted Score (out of 60):</b>		28	52	49	38

#### 4.4 Treatment Technologies

To evaluate the primary treatment technologies, four criteria were chosen: treatment level, cost, maintenance requirement, and treatment time. Regarding importance for each criterion, treatment level remains the most important criterion. Specific water quality standards must be met before the collected water is reused at the Zoo, and this remains important to both the public for human safety and the zoo for animal safety. Cost was chosen as the next most important criterion. While cost will vary for each treatment technology, some capital investment must be made for the treatment process. Some technologies may be too expensive to consider, so high-cost alternatives are important to address. The third most important criterion is maintenance requirements. Maintenance requirements include mechanical upkeep and parts replacement for various functions of each treatment technology. Maintenance intervals will also

vary for each treatment technology. Lastly, treatment time was chosen as the least important alternative. Due to the variation of rainfall events, treatment technologies must process water consistently on demand. Technologies not able to treat efficiently enough may not be considered for the treatment train. However, the treatment system will pull from storage tanks and can run continuously, justifying its position as the least important criterion.

#### 4.4.1 Rapid Sand Filtration

Sand filtration is a well-established technology in the water treatment process. Solids, microorganisms, and heavy metals are removed from the flow path as water travels through the filter media. Sand filters require a relatively large footprint to accommodate high flow rates, with most systems treating water at about 5 gpm/sq ft. Commercial sand filters cost an average of \$32,000 USD for installation and \$5,000 annually for a 79", 88 sqft system. Maintenance is relatively low, but systems do require backwashes weekly or monthly depending on use. Treatment performance is reliable, with high reduction in TSS and up to 1 log reduction in BOD.

#### 4.4.2 Microfiltration

Microfiltration is an alternative to sand filtration, and comparative data presents interesting findings. Installation cost, likely less than \$100,000, is on the expensive side of the alternatives, but operational and maintenance costs prove to be less than others. Maintenance intervals are relatively long, only needing membrane replacement once a month depending on system use. Filters must be backflushed or replaced periodically, and trapped solids must be disposed of after filter cleaning. Microfiltration systems generally operate at low flow rates, so many units are needed to improve overall system efficiency.

#### 4.4.3 Cellulose-Based Filtration

Cellulose-based filtration, a natural comparison to the two previous filtration technologies, is more of a mixed bag. Because there is less field testing and operational information, much engineering design work is required for system integration. However, obtaining cellulose materials is relatively cheap and easy, proving this alternative to be greener and more cost efficient. Maintenance intervals are expected to be more frequent than other

alternatives due to constant sourcing and replacement of cellulose materials. Flow rate is expected to reflect that of microfiltration, leaning toward the low-flow region. As a result, system size may be larger than feasible at this site.

#### 4.4.4 Ultraviolet

UV treatment remains effective regarding microbial treatment. Additionally, systems are relatively inexpensive as reactors and replacement bulbs are both readily available. Sitting at the final treatment step in the treatment train, small UV systems provide efficient disinfection performance to flowing water at acceptable flow rates. Maintenance intervals are low as systems are turned on for hours of use and require less than 10 minutes of warm-up time. Bulb replacement and quartz sleeve fouling cleaning must occur about once a month depending on use.

#### 4.4.5 Chlorination

Chlorination is a polarizing technology. Overuse or misuse can lead to problems. On the other hand, chlorination is relatively effective and inexpensive. Due to the constant monitoring operation is known to cause headaches. Because there are many forms of chlorine addition and monitoring, costs can range greatly. Capital and annual costs are for a continuously monitored and automatic feeding system that utilizes a 12.5% hypochlorite solution. Disinfection performance is notably less than that of UV treatment: however, application for each technology will vary depending on treatment system location within the full treatment train.

#### 4.4.6 Comparative and Alternative Analysis for Treatment Technologies

Comparative data for the primary treatment technologies is detailed in Table 8. Each technology is ranked on a scale of 1-5 and multiplied by the designated weight for each criterion to generate the final score of the five technologies, forming the complete alternative analysis detailed in Table 9.

Table 8: Comparative Analysis for Primary Treatment Technologies

Comparative Data for Primary Treatment Technologies					
	Filtration			Disinfection	
	Sand Filtration	Microfiltration	Cellulose-Based Filtration	Ultraviolet	Chlorination
<b>Installation Cost</b>	\$32,000	\$70,000	\$90,000	\$5,000	\$30,000
<b>Annual Cost</b>	\$5,000	\$2,500	\$1,000	\$600	\$8,000
<b>VOC (%)</b>	0.0	0.0	65.0	0.0	0.0
<b>BOD (%)</b>	90.0	75.0	50.0	99.9	45.0
<b>Maintenance Interval Requirement</b>	Weekly/Monthly	Monthly	Weekly	Monthly	Daily to Weekly
<b>Treatment Flow Rate (gpm/sq ft)</b>	5	2	0.5	16.7	20

Table 9: Alternative Analysis for Primary Treatment Technologies

Primary Treatment Alternative Analysis						
Criteria	Weight	Filtration			Disinfection	
		Sand Filtration	Microfiltration	Cellulose-Based Filtration	Ultraviolet	Chlorination
<b>Treatment Level</b>	10	5(12)	4 (40)	1 (4)	2 (8)	4 (40)
<b>Cost</b>	7	4 (6)	3 (9)	4 (12)	1 (3)	3 (9)
<b>Maintenance</b>	4	3 (4)	3 (6)	1 (2)	4 (8)	3 (6)
<b>Treatment Flow Rate</b>	1	3 (2)	3 (3)	4 (4)	1 (1)	3 (3)
<b>Unweighted Score</b>		15	12	7	16	10
<b>Weighted Score (out of 110)</b>		93	72	46	79	40

## Final Design Recommendations

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After analyzing multiple technologies for capture, pre and primary treatment, and storage, Fritz Consulting recommends that the Cincinnati Zoo and Botanical Garden use catch basins with french drains for capture (Alternative 4), hydrodynamic separators as the primary technology used for pretreatment and sediment filter bags as initial pretreatment directly following collection wherever applicable (Alternatives 2 and 3), a precast concrete tank housing pumps and construct it underneath the existing Goetze Animal Health Center to serve as storage, and a treatment train utilizing both sand filtration, UV systems, and chlorination (Alternatives 1, 4, and 5). The logistics of the recommended water reuse system will be outlined during the design phase of the process. Fritz Consulting predicts that by implementing these alternatives, CZBG will take a major step toward their goal of achieving net-zero water usage by 2025.

### 5.1 Secondary Stormwater Analysis

Historical rain gauge data for the Cincinnati Zoo property had been collected by the metropolitan sewer district of greater Cincinnati. The data was from 2003 through September 2022. The data was analyzed in excel against different runoff coefficients, pumping rates, tank size and watershed area. The goal of the created model was to show the variance in overflow volumes for the different constraints previously mentioned. Overflow volume was defined as the amount of runoff from a given storm event that does not get captured in the designed tank.

#### 5.1.1 Rain Gauge Data Analysis

Fritz Consulting was provided with 19 years of data from a rain gauge located at CZBG. The rainfall data was recorded in 5-minute time intervals. Only intervals with recorded rainfall were included in the dataset. This rainfall data was analyzed over the 19-year study period from 2003 to 2021 to describe data variation and determine any noticeable rainfall trends (see Figure 16).

Analysis of the provided rain gauge data did not reveal any temporal trends in annual rainfall, but it did demonstrate the tremendous variation in annual rainfall that Cincinnati experiences. The minimum and maximum annual rainfall values -- 34.6 inches in 2010, and 68.8

inches in 2011, respectively -- nearly vary by a factor of two. The mean annual rainfall across the 19-year period was 46.2 inches. These results demonstrate the need for a storage tank that is equipped to handle significant fluctuations in rainfall volume and intensity.

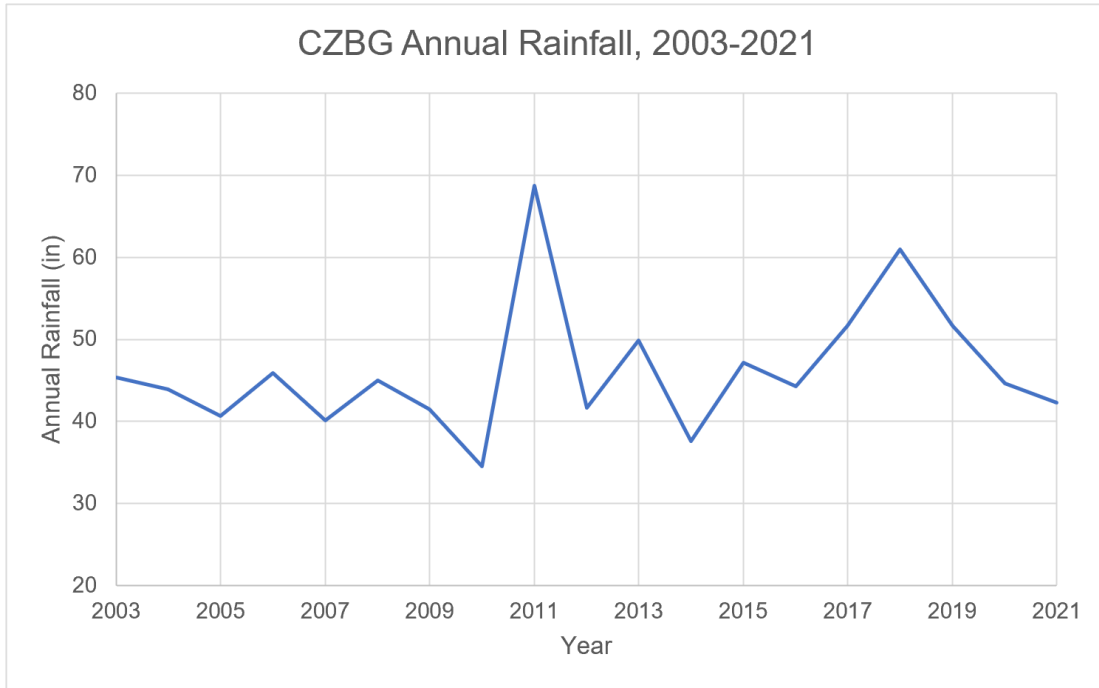


Figure 16: CZBG Annual Rainfall from 2003-2021

### 5.1.2 Daily Storage Tank Model

Using Microsoft Excel, a model was created to simulate the response of the proposed Jungle Trails storage tank to the 19 years of historic rain gauge data. The model inputs included storage tank capacity, watershed area, watershed runoff coefficient (the percentage of rainfall that is converted into direct runoff), and pumping rate leaving the tank. The default model inputs are summarized in Table 10.

Table 10: Default parameter values for daily rainfall model

Parameter	Value	Unit
Pumping Rate	250	gpm
Watershed Size	14.8	acre
Runoff Coefficient	0.51	
Tank Size	183,000	gal

The 5-minute rain gauge data provided to Fritz Consulting was combined into daily total rainfall values, spanning from January 1, 2003 to December 31, 2021. The following assumptions were made to create the model:

- All direct runoff from the 14.8-acre Jungle Trails watershed enters the Jungle Trails storage tank. No direct runoff is diverted or stored elsewhere.
- There is no lag time between rainfall, direct runoff generation, and entry of runoff into the storage tank.
- The tank is equipped with a single pump possessing a single pumping rate. This assumption could be revisited in future model iterations.
- The pump begins operation as soon as runoff enters the storage tank, and continues operation until the tank is fully empty.
- When tank overflow occurs, the tank storage is set equal to the maximum tank capacity (183,000 gallon) for the start of the next day. The tank storage can never drop below zero or above the maximum tank capacity.
- The storage level within the tank each day is calculated by the addition of the previous day's storage and runoff volume generated minus the volume pumped.
- The pumping rate leaving the Jungle Trails tank is not constrained by the level within the Elephant Trek tank.

This model was simulated over the 19-year historical dataset to generate statistics on volume of capture and overflow from the storage tank, rainfall, and pumping. The results are summarized in Table 11. Further analysis of the hourly storage tank model revealed that the predicted overflow was artificially low. Use of a daily time step essentially created an imaginary extra storage volume by allowing the pump to “catch up” to the runoff generated throughout the day. As a result, the model predicted an average of only 80,804 gallons of overflow per year.

Table 11: Daily tank model results

Daily Tank Model Summary, 2003-2021	
Parameter	Value
Days with Storage Accumulation	0.7%
Days with Pump Running	41.7%
Annual Overflow (gal)	80,804
Days with Overflow	16
Days with Rainfall	41.5%
Days with > 0.5 in	8.5%
Days with > 1.0 in	3.1%
Days with > 2.0 in	0.5%
Maximum Daily Rainfall (in)	4.168
Average Annual Rainfall (in)	46.2

### 5.1.3 Hourly Storage Tank Model

Due to the sensitivity limitations of the daily storage tank model, the need for a smaller model time step became clear. Thus, Fritz Consulting created an hourly storage tank model to test the accuracy of the daily model’s results. The hourly model was created with the same inputs and assumptions as the daily model. The parameters of particular interest to Fritz Consulting were the percent capture of the tank, the total annual volume of overflow from the tank, and the relationship of rainfall to tank overflow. The model results, with input values of a 250 gallon per minute pumping rate and runoff coefficient of 0.51, are summarized in Table 12 below.

Table 12: Hourly storage tank model results at 250 gpm and C = 0.51

Hourly Model Results – 250 gpm, C=0.51			
Parameter	Min	Average	Max
Rainfall (in)	260,377	1,138,943	2,292,904
Percent Capture	104,578	830,188	1,705,808
Tank Overflow (gal)	44,895	639,258	1,393,286
Volume Captured (gal)	32,895	508,000	1,134,569

These results display tremendous variability. The maximum annual tank overflow (2017) is more than 34 times larger than the minimum (2014) over the 19-year study period. The volume captured by the tank varies by a factor of 2. Furthermore, the hourly model predicts an

average of 508,000 gallons of overflow annually -- dramatically more than the roughly 80,000 gallons predicted by the daily model. The hourly model eliminates the imaginary storage margin created by the inherent assumptions of the daily model. During an intense rain event, or one where the tank already is holding water, the tank may be overwhelmed in just a few hours of rain. Where the daily model allowed 24 hours for the pump to “catch up” to adverse conditions, the hourly model allows just one.

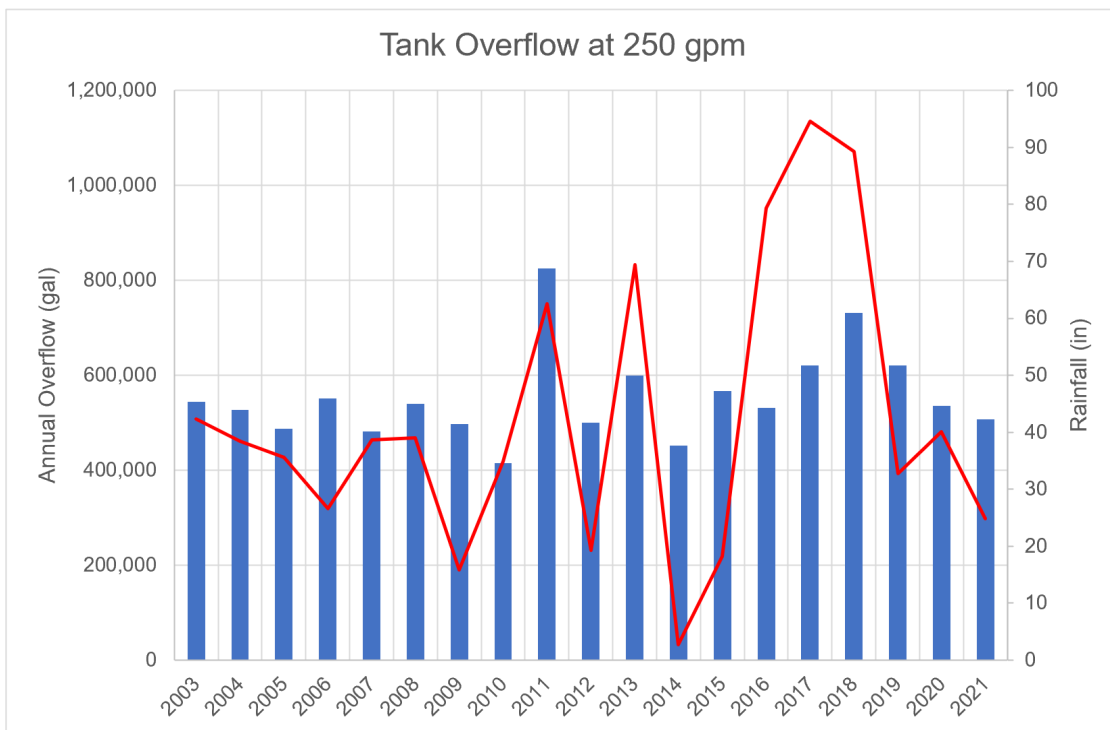


Figure 17: Tank overflow predicted by the hourly model, 2003-2021

Figure 17 above shows the variance of the storage tank’s response to rainfall over the course of the historic dataset. This statistic reveals the extent to which the proposed tank will discharge excess water to the downstream combined sewer system. According to the model, the percent capture of the storage tank varies between 99.6% and 89.3% over the course of the study period (Figure 18). The model predicts that, even in years of intense rainfall, such a tank would prevent millions of gallons of stormwater from overwhelming the combined sewer system and creating environmental hazards -- such as sewer backups into homes and businesses and overflow of combined sewage into natural waterways.

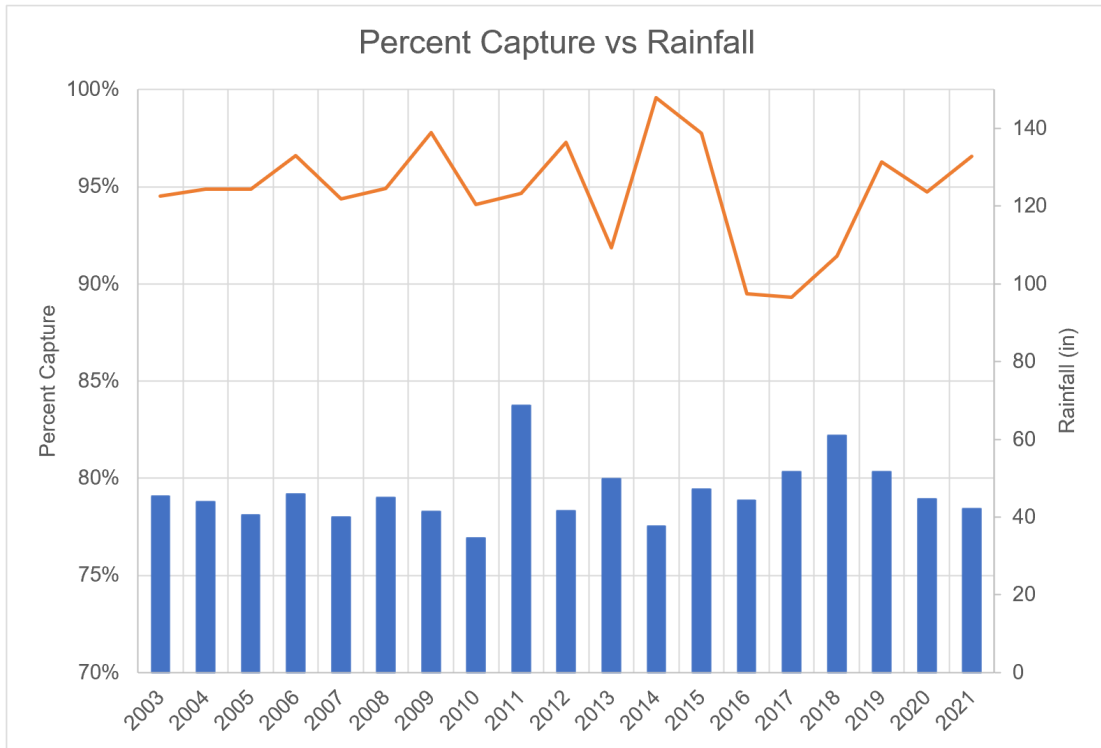


Figure 18: Tank percent capture predicted by the hourly model, 2003-2021

### 5.1.4 Sensitivity Analysis

A sensitivity analysis was performed on the impact of watershed runoff coefficient and tank pumping rate on tank overflow volume. A range of pumping rates between 100 and 500 gallons per minute were examined over the study period of 2003 to 2021 (Table 13).

Table 13: Hourly storage tank model result:  $C = 0.51$ , variable pumping rates

Hourly Model Results, 2003-2021				
Parameter	Min	Average	Max	% of 250 gpm
Overflow at 100 gpm	260,377	1,138,943	2,292,904	224%
Overflow at 150 gpm	104,578	830,188	1,705,808	163%
Overflow at 200 gpm	44,895	639,258	1,393,286	126%
Overflow at 250 gpm	32,895	508,000	1,134,569	100%
Overflow at 500 gpm	0	191,211	699,756	38%

The pumping rate chosen had a significant effect on the overflow volume from the tank. An increase in pumping rate from 250 to 500 gallons per minute, for instance, resulted in a 62% decrease in overflow. If CZBG desires to craft specific benchmarks related to overflow

prevention or capture volume, these results could be very useful. In the interest of energy efficiency, CZBG has expressed a desire to keep pumping rates at or below 500 gallons per minute in the proposed Jungle Trails tank. With this in mind, the possibility of variable pumping rates is very attractive. Lower pumping rates, such as 150 or 250 gallons per minute, could largely handle smaller rain events, while a 500 gallon-per-minute pump could capture the vast majority of runoff even during intense storms.

A sensitivity analysis was also performed on the impact of runoff coefficient on tank overflow. The annual overflow over the 19-year study period was analyzed using runoff coefficient values of 0.51, 0.55, and 0.60, as shown in Figure 19.

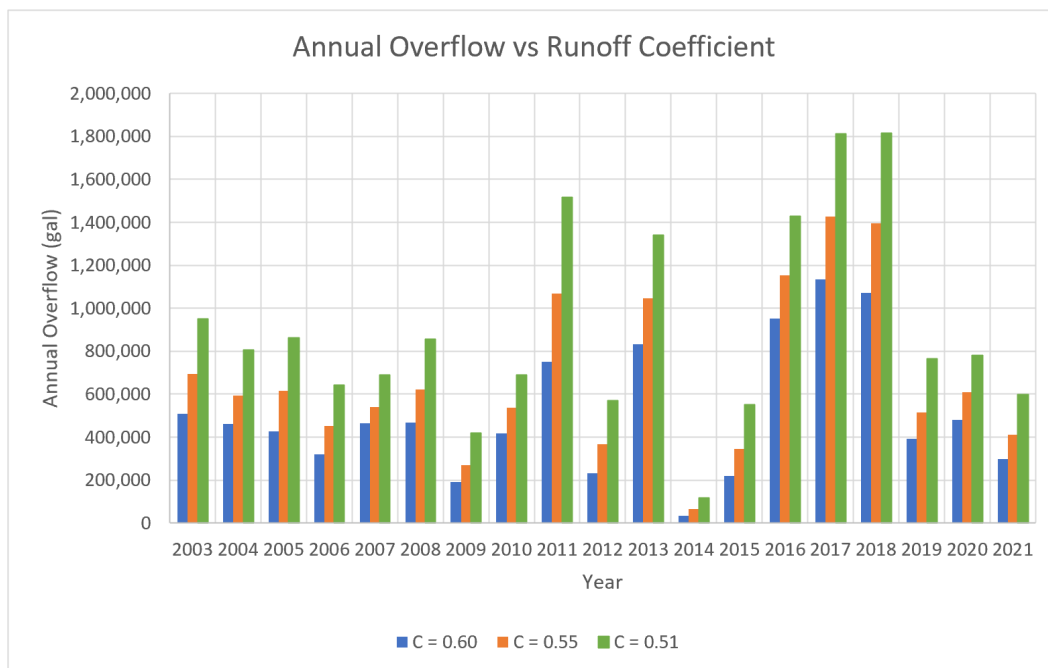


Figure 19: Tank percent capture predicted by the hourly model, 2003-2021

These results demonstrate an exponential effect of runoff coefficient on overflow. A 17% increase in the runoff coefficient from 0.51 to 0.60 resulted in a 78% increase in annual overflow from 508,000 to 905,144 gallons. CZBG and Fritz Consulting have currently estimated a runoff coefficient value of 0.51 for the Jungle Trails watershed, based on approximate estimates of land uses. Given the significant impact produced by even a small change in watershed runoff coefficient, it may be in CZBG’s best interest to generate a more exact runoff coefficient value for future calculations.

## 5.2 Additional Treatment Technologies

Following the design recommendation review, it was requested that an additional treatment technology be researched for implementation consideration. Specifically, a sponsor requested the use of hydroponic treatment ponds be researched due to their effective treatment capabilities. Subsets of these systems, including floating treatment wetlands, have been utilized in stormwater pretreatment applications with great success. Unique treatment properties that these techniques offer may prove valuable for and can further progress the Cincinnati Zoo’s “net zero” water efforts.

### 5.2.1 Floating Treatment Wetlands

Floating treatment wetlands (FTW) are a relatively new variant of traditional wetland and pond treatment technologies and offer a number of advantages when compared. Like traditional treatment wetlands, FTWs utilize macrophytes, or plants, to remove heavy metals and other pollutants. Where FTWs separate themselves from other treatment wetlands is given in its name and lies in the method the macrophytes are placed in the system. Instead of plants rooted in the soil beneath shallow ponds, FTWs have floating raft-like platforms in which plants are rooted and permanently in contact with water, as shown in Figure 20. This technique proves to allow for consistent treatment across the inevitable wide range of flows that erratic hydrologic systems bring. This system also leads to a number of other advantages, including low maintenance, passive operation, and overall aesthetic (Headley & Tanner, 2008). It is important to note that built up solids and sludge would need to be removed occasionally, so designing a system with solids removal in mind is recommended.

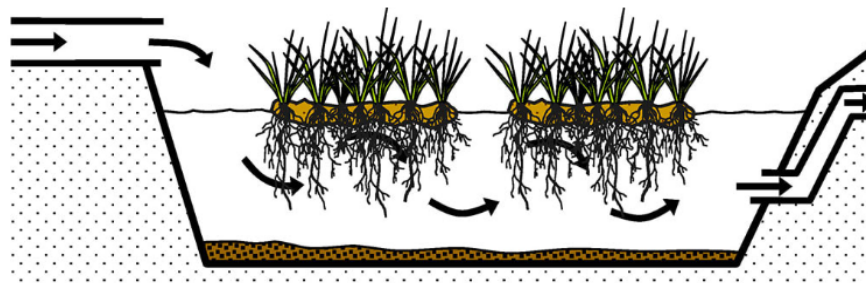


Figure 20: Floating treatment wetland diagram (Source: Headley & Tanner, 2008)

One limitation to this technology is its less effective at removing finer particles and contaminants. Despite this, FTWs are proven to be an effective pretreatment technology, meeting similar requirements for other technologies and providing water quality that can pass directly to the primary treatment train. It was found that 86% of fecal coliform was removed in a field-scale study in Mexico and 78% of TSS was removed in a full-scale study in France. The TSS removal efficiency nearly meets that of the hydrodynamic separator, all while offering relatively high fecal coliform removal compared to 0% fecal coliform removal for the hydrodynamic separator (Sharma et al., 2021).

### 5.3 Cost Analysis

Fritz Consulting has conducted a cost analysis of the recommended stormwater reuse for the Jungle Trails watershed. For the purpose of our cost estimate, we were focused on the material and installation costs of the items directly related to the capture and reuse of stormwater. Other costs related to site preparation, excavation, pavement, and other site improvements were not considered, however, they could have a significant impact on overall cost. Unless stated otherwise, all pricing information was gathered from Terrex Development and Construction, who conducted a complete design development estimate for the Elephant Trek project in 2021. It is expected that these prices will remain similar and are accurate. Our design cost estimate can be broken down into 3 main parts: stormwater capture and conveyance, storm water pretreatment and storage, and water reuse distribution network. Primary treatment and storage of the polished water will be completed using the existing utilities located at Elephant Trek and these costs are not included in our estimate. The total cost of \$1,702,099 and associated costs from each part can be found in Table 14. A more in-depth cost breakdown has been performed in the following sections.

Table 14: Total Project Costs for Jungle Trails

Total Project Costs – Jungle Trails	
Description	Cost
Storm Water Capture and Conveyance	\$880,404
Storm Water Pretreatment and Storage	\$551,844
Water Reuse Distribution Network	\$269,851
<b>Total Cost:</b>	<b>\$1,702,099</b>

### 5.3.1 Stormwater Capture and Conveyance

A cost estimate was performed for the designed stormwater capture and conveyance system. 54 catch basins, with a total cost of \$93,960 for material and installation, are required to capture the stormwater throughout the Jungle Trails watershed. Once the stormwater has been captured, storm pipes ranging in size from 8” to 24” will be required to transport the water. 6399 LF or gravel backfill is needed for the storm pipes and 33 manholes are also required as part of the design. The total cost of stormwater capture and conveyance is \$880,404 (Table 15).

Table 15: Stormwater Capture and Conveyance Costs

Stormwater Capture and Conveyance				
Description	Quantity	Unit	Unit Cost	Totals
Storm 8”	65	LF	\$58.94	\$3,831
Storm 12”	4022	LF	\$74.75	\$300,645
Storm 18”	1273	LF	\$86.25	\$109,796
Storm 24”	1039	LF	\$161.58	\$167,882
Storm Gravel Backfill	6399	LF	\$13.36	\$85,491
Catch Basins – 2’ x 2’	54	EA	\$1,7400.00	\$93,960
Manhole	33	EA	\$3,600.00	\$118,800
			<b>Total:</b>	<b>\$880,404</b>

### 5.3.2 Stormwater Pretreatment and Storage

A FlexStorm filter bag will be required at each of the 54 catch basins, yielding a total cost of \$67,500. Cost estimates for filter bags were gathered from Ferguson. One AquaSwirl AS-12

hydrodynamic separator is estimated to cost \$99,500. The 283,000-gallon underground storage tank, composed of 213 cubic yards of precast concrete, will cost \$256,144. The tank dimensions are 40' x 61' x 10' with a top and bottom and 10" thick walls. 3 submersible grinder pumps, capable of 150 GPM for the calculated head, will be used in parallel to pump the raw water to the larger storage tank in Elephant Trek. The total material and installation cost of stormwater pretreatment and storage is \$551,844 (Table 16).

*Table 16: Stormwater Pretreatment and Storage Costs*

Stormwater Pretreatment and Storage				
Description	Quantity	Unit	Unit Cost	Totals
Storage, Precast Concrete Tank	213	CY	\$1,200.00	\$256,144
FlexStorm Filter Bag – 2' x 2'	54	EA	\$1,250.00	\$67,500
AquaSwirl Separator	1	EA	\$99,500.00	\$99,500
Duplex Sub Grinder Pump (150 GPM)	3	EA	\$42,900.00	\$128,700
			<b>Total:</b>	\$551,844

### 5.3.3 Water Reuse Distribution Network

The polished water stored at Elephant Trek will be distributed back to the Jungle Trails area using the proposed design of 4" water reuse mains. 2906 LF of the 4" water reuse pipe at a unit price of \$79.50 per LF is required for transport. The total cost of water reuse pipe and gravel backfill is \$269,851 (Table 17). This amount does not include the price of pumps required for distribution of the polished water.

*Table 17: Water Reuse Distribution Network Costs*

Water Reuse Distribution Network				
Description	Quantity	Unit	Unit Cost	Totals
4" Water Reuse Main	2906	LF	\$79.50	\$231,027
Water Reuse Gravel Backfill	2906	LF	\$13.36	\$38,824
			<b>Total:</b>	\$269,851

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## Appendices

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### Equation 1: The Rational Method

Used to calculate peak runoff flow rate  $\text{ft}^3$

$$Q = I * A * C$$

$$\begin{aligned} Q &= \text{Runoff rate (ft}^3/\text{day)} \\ I &= \text{Rainfall intensity (ft/day)} \\ A &= \text{Watershed area (ft}^2\text{)} \end{aligned}$$

#### Example Calculation for 24-hr, 25-year storm

$I = 6.30 \text{ in/day}$  or  $0.26 \text{ in/hr}$

$A = 14.25 \text{ acres}$

$C = 0.55$

.....

$$Q = (0.26 \text{ in/hr}) * (14.25 \text{ ac}) * 0.55 = 2.05 \text{ ac} - \text{in/hr}$$

$$Q = 2.05 \text{ ft}^3/\text{s} * (7.481 \text{ gal/ft}^3) * (86400 \text{ s/day}) = 1.32 \text{ million gallons per day}$$

Note: 1 ac-in/hr is assumed to be equal to 1  $\text{ft}^3/\text{sec}$  (true conversion factor is 1.008)

### Acknowledgements:

Fritz Consulting would like to thank Mark Fisher and the entire team at CZBG, Jeff Koehn and Howard Bowen and the engineering team at IBI Group, and Dr. McAvoy and Dr. Buchberger at the University of Cincinnati.

### Vision Statement:

"Innovating solutions to help communities utilize and preserve their natural water resources for a more sustainable future"

## Organizational Chart:

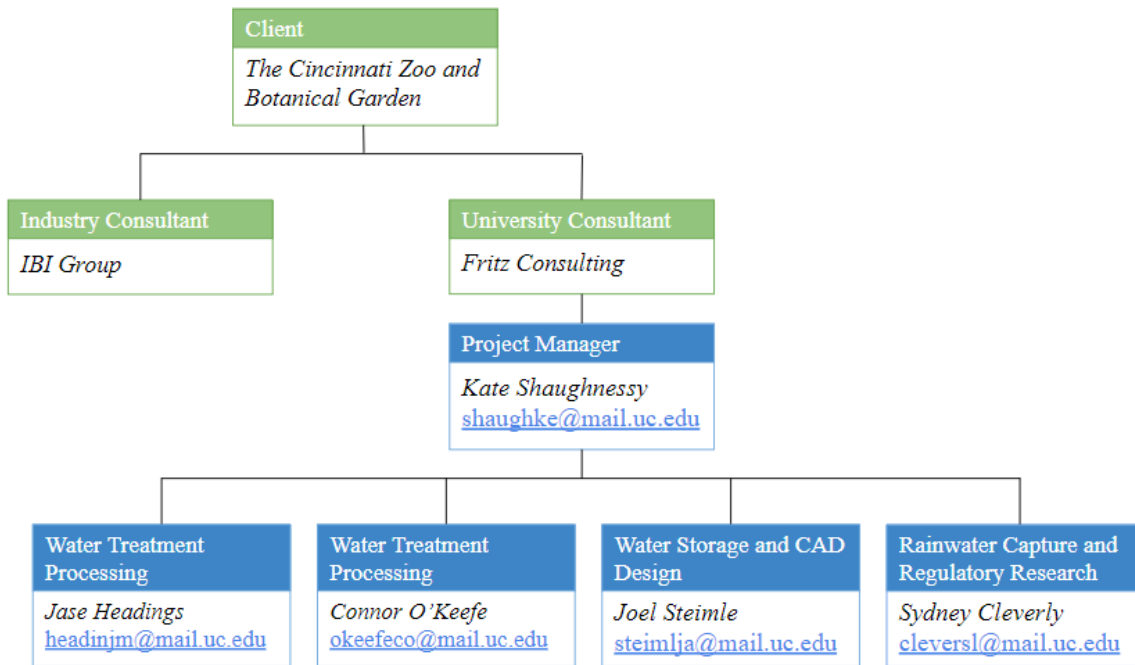


Figure 21: Organizational Chart

## Personal Backgrounds

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Sydney Cleverly is a fifth year Environmental Engineering major at the University of Cincinnati. She has completed several co-ops in heavy industry. She worked summer rotations with Martin Marietta, aggregates mining. There she learned local, state, and federal compliance laws across Ohio, Kentucky, and West Virginia. Drafting permits, BMP's, and internal audits were accompanied by quality control and water sample collection for discharge monitoring reports (DMRs). Between the rotations at Martin Marietta, she worked at Pixelle Specialty Solutions in Chillicothe, OH. There she was involved in the Environmental Health and Safety department. During her time there she continued DMR reporting for the on-site wastewater treatment operation. Amongst the reports completed, a federal Tier II, SARA-312 was completed and transferred to an online data collection system, Encamp. Designing and implementing a new method of Title-V data collection was a large success, creating communication between the EHS department and every area of the mill governed by title-v regulations.



Connor O'Keefe is a fifth-year Environmental Engineering major at the University of Cincinnati. He has completed several co-ops in a variety of industries including water quality, wastewater construction, and environmental health and safety. At Ulliman Schutte, Connor was a co-op engineer working on pump system upgrades at Blue Plains AWWTP in Washington, DC. At Burndy-Hubbell, he worked in Littleton, NH where he reviewed safety procedures and was involved with solid and hazardous waste management. In addition to his experience in industry, Connor has also performed research at UC, focusing on biological treatment technologies for agricultural water reuse as a part of the National Alliance for Water Innovation (NAWI).



Jase Headings is a fifth year Environmental Engineering major at the University of Cincinnati. Jase has completed three co-op rotations at a chemical manufacturer working in the quality control and research & development labs. There, he strengthened his lab technique, report writing, and critical thinking skills with hands-on experience, learning from the highest level engineers and the most efficient production operators. Following this experience, Jase took his career another direction, pursuing a customer facing role as an applications engineer. Tasks included responding to customer inquiries via phone and email and leading meetings to discuss custom applications and projects. After graduation, Jase plans to continue in the sales engineering field and pursue a career in project and account management.



Kate Shaughnessy is a fifth year Environmental Engineering major at the University of Cincinnati. Kate is also receiving her certification in GIS through the University. She has completed 5 co-op rotations, working at 4 different companies in 2 countries. She worked with ceramic matrix composites at GE Aviation in their environmental health and safety department. Then, she shifted toward water, working on combined sewer overflow (CSO) and wastewater treatment projects with the Metropolitan Sewer Districts of Cincinnati, Dayton, and Louisville with Clear Consulting, inc. She worked with Arup in San Francisco, California, and continued working on CSO projects, while working on flood prevention and risk management projects across the world. She spent her last two co-op rotations in Germany, working in an energy and climate research lab at Forschungszentrum Juelich. There she communicated, presented, and trained coworkers in German, while researching aerosol dispersion patterns and filtration methods.



Joel Steimle is a fifth year Environmental Engineering major at the University of Cincinnati. Joel completed one co-op rotation at Warren County Soil and Water Conservation District in Lebanon, OH where he performed inspections of stormwater retention/detention basins, outfalls, and other stormwater structures. Joel also completed four co-op rotations with the engineering consulting firm Hazen and Sawyer in Cincinnati, OH. There he gained experience working on wastewater, drinking water, conveyance, and modeling projects. In this role, Joel had the opportunity to design and route piping, create and review construction drawings, perform site visits, and utilize software such as ArcGIS, PCSWMM, Bluebeam, and Excel. After graduation, Joel will be moving to Lexington, KY and working for Hazen and Sawyer.

# Kate Shaughnessy

Email: shaughke@mail.uc.edu Phone: 412-328-4622

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<b>Education</b>	<b>University of Cincinnati</b> - Bachelor of Science, Environmental Engineering - University Honors Program - Cincinnatus, CEAS Alumni, and National Merit Scholar - Cumulative GPA: 3.98	<i>Expected Graduation May 2023</i>
<b>Employment</b>	<b>Forschungszentrum Jülich</b> - Conversed in technical and casual German with colleagues throughout the duration of the co-op - Performed experiments to improve aerosol particle filtration methods in failed nuclear reactors - Trained new coworkers in German on the theory and step by step process of experiments <b>Arup</b> - Created a sewer system model in Infoworks ICM and reduced storm peak flows through pipes - Modeled flood inundation boundaries using HEC-RAS to prove site compliance - Updated boundaries to comply with local regulations for a proposed 5000 acre PV solar farm - Delineated catchment areas and land use for project sites in GIS and prevented 100 year site flood <b>Clear Consulting, Inc.</b> - Monitored wastewater flow for the Metropolitan Sewer District of Greater Cincinnati - Performed risk assessments for City of Dayton's water reclamation facility - Updated storm, flood, and wastewater data for CSOs and SSOs in GIS applications - Refurbished odor covers to save cost for City of Dayton's Water Treatment Facility <b>GE Aviation</b>	<i>Jan 2022-Jul 2022</i> <i>Jun 2021-Aug 2021</i> <i>Aug 2020-Jan 2021</i> <i>Jan 2020-May 2020</i>
<b>Organizations</b>	<b>Engineers Without Borders</b> - Former Vice President of Operations and Secretary - Fundraised over \$3000 for water, solar, and sanitation projects in 3 Tanzanian communities - Updated groundwater storage tank designs in AutoCAD - Traveled to Tanzania for 2 weeks to assess system and strengthen community relations <b>One For The World</b> - Vice President of Charities - Trained executive board and club members on recognizing effective charities - Educated students on the most efficient ways to donate to communities in need	<i>Aug 2018-Present</i> <i>Aug 2020-May 2021</i>
<b>Certificates</b>	<b>Geography Information Sciences (GIS) Certificate</b> - Develops skills for GIS use in environmental and urban planning applications - Strengthens spatial analysis and graphic presentation skills	<i>Completed by May 2023</i>
<b>Languages</b>	<b>German (Fluent)</b> - Received Outstanding Achievement Award from German Studies Department - Participated in a 3 week German Intensive in Aachen, Germany - Certified by exam from FH Aachen University of Applied Sciences	<i>Sep 2012-Present</i>

# Sydney Cleverly

(937)607-0132 • Cincinnati, OH • cleversl@mail.uc.edu • [www.linkedin.com/in/Sydney-Cleverly](http://www.linkedin.com/in/Sydney-Cleverly)

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## EXPERIENCE

### **Environmental and Land Management Intern**

06/22-08/22

06/21-08/21

Martin Marietta Materials | West Chester, OH

- Drafted several updated environmental compliance plans
- Researched and updated office manual containing permit regulations
- Assisted surveying sections of property for future mining operations
- Organized permits, operation manuals, and applications
- Conducted geological research on limestone deposits through Kentucky
- Traveled to different mining operations to participate in internal audits
- Collected and prepared water samples from several mining sediment ponds
- Prepared required documents for permit applications

### **Environmental/EHS Intern**

01/22-04/22

Pixelle Specialty Solutions | Chillicothe, OH

- Distributed weekly reports on the carbon emissions monitoring systems
- Completed the SARA 312 chemical inventory report for each operations location
- Implemented a new Title V report inventory system
- Reviewed and filed monthly water sample data for the discharge monitoring report

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## PROJECTS

### **Standard Operating Procedures Manual**

06/21-08/21

Martin Marietta Materials | West Chester, OH

- Developed a standard operating procedure for a stockpile yard in Kentucky
- Gathered geographical data required for site location maps
- Updated contact information for state and local oil spill requirements
- Collaborated with the Sr. Environmental Engineer and V.P.G.M of the Ohio district on final approval

### **Permeable Concrete Absorption- Engineering Models 3**

01/20-04/20

University of Cincinnati | Cincinnati, OH

- Researched the relationship between a type of concrete permeability and the effectiveness of absorbing rainfall
- Developed a code in MATLAB showing the relationship between different concretes and their ability to absorb specified rainfall amounts
- Motivated by finding a concrete for city areas like Cincinnati where there are periods of heavy rainfall and constant high traffic, causing street erosion

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## EDUCATION

University of Cincinnati | Bachelor of Science in Environmental Engineering

05/23

- GPA: 3.0/4.0
- Minor of Communication
- Treasurer, UC Cycling Club; Society of Women Engineers; Society of Environmental Engineers

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## SKILLS

SWMM | MATLAB | AutoCAD | EPANET | ArcGIS | IBM Cloud Data Analysis Certification

# JOEL STEIMLE

6568 Greenfield Drive, Cincinnati OH 45224 | (513) 470-6233 | josteimle@gmail.com

## EDUCATION

University of Cincinnati

Class of 2023

Bachelor of Science – Environmental Engineering

GPA 3.98

## PROFESSIONAL EXPERIENCE

**Technician | Hazen and Sawyer**

January 2020 – August 2022 (four rotations)

- Helped to advance over 50 projects relating to wastewater treatment plants, water treatment facilities, stormwater management, and water conveyance systems
- Designed, routed, and sized potable and nonpotable water systems for three buildings at Dayton Water Reclamation Facility
- Developed training automation system that reduced labor time by 75%
- Reviewed GIS and topographic survey data to identify areas sensitive to vehicle damage along Washington Aqueduct in Washington, D.C.
- Created presentation for West Virginia water utility to assess treatability of new drinking water source and summarize new PFAS standards
- Utilized record drawings to create GIS model of Marietta, OH collection system
- Developed system to document, track, and collect data on storm events at Cincinnati's Mill Creek Wastewater Treatment Plant
- Collected wastewater quality data on three-day sampling trip in Peru, IN
- Reviewed record plans to estimate total heat demand for 28 buildings at Dayton WRF
- Led efforts to estimate annual carbon emissions at Indianapolis Airport Authority
- Developed routing plans for hot water and natural gas utilities using AutoCAD

**Natural Resource Intern | Warren County Soil & Water Conservation District** Summer 2021

- Performed stormwater basin and outfall inspections to fulfill MS4 permit requirements
- Classified stream macroinvertebrates to assess water quality of rivers and streams
- Utilized equipment such as YSI probe, plankton net and secchi disk to analyze Caesar Creek Lake and monitor potential for harmful algal blooms
- Advanced conservation education by facilitating community outreach events

**Student Researcher | University of Cincinnati**

Summer 2019

- Project Title: Micromachined Chemical Sensor for Seafloor Environment
- Modeled and designed electrodes to be used in ion conductivity testing
- Operated waterjet cutter and SEM to prepare and characterize ceramic samples
- Created and presented scientific poster to communicate results to industry professionals

## LEADERSHIP

**President, Student Leader | Bridges International**

2019 - Present

- Plan and lead weekly events geared towards welcoming and engaging international students at University of Cincinnati
- Manage administrative duties of organization, such as budget requests and scheduling

**SOFTWARE SKILLS:** ArcGIS, AutoCAD, PCSWMM, EPANET, MATLAB, Excel, Bluebeam

## Connor M. O’Keefe

850 Dorgene Lane Cincinnati, Ohio 45244 513-568-7444 okeefeco@mail.uc.edu

### EDUCATION

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#### UNIVERSITY OF CINCINNATI, Cincinnati, OH

*Bachelor of Science, Environmental Engineering*

- Expected Graduation: May 2023
- GPA: 3.41 (5 semesters on Dean’s List)
- Relevant Courses: Biology, Water Treatment, Hydrology, GIS, Fluid Mechanics, Geology

### PROFESSIONAL EXPERIENCE

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#### BURNDY – HUBBELL, Littleton, NH

*EHS Co-op, May – August 2022*

- Inventoried chemicals plantwide and updated safety data sheets.
- Conducted root cause analysis on workplace injuries to implement preventative controls.
- Led 10 safety training sessions for over 50 new employees on proper PPE and LOTO procedures.

#### ULLIMAN SCHUTTE CONSTRUCTION, Washington, D.C.

*Co-op Engineer, January – May 2022*

- Worked as a member of the project engineering team to provide upgrades at the world’s largest AWWTP.
- Requested quotes, drafted purchase orders, and coordinated delivery of project materials.
- Performed detailed startup procedures and hourly monitoring for the implementation of two new filter influent pumps, increasing total pump efficiency and decreasing energy usage.

#### WHALE’S TALE WATERPARK, Lincoln, NH

*Water Tester (Internship), May – August 2021*

- Tested water quality conditions of 14 pools using a digital photometer, measuring levels of pH, free chlorine, alkalinity, and calcium hardness.
- Balanced water chemistry by adding calculated amounts of sodium bicarbonate and calcium chloride.
- Improved water treatment efficiency by analyzing pool volumes and chemical feed flowrates.

#### GREENLIGHT OPTICS, Loveland, OH

*Optical Assembly Technician, July – August 2019*

- Tested laser optical modules used for handheld medical devices.
- Reduced product error through visual inspection of over 100 optical components per day and identifying the cause of defects.
- Assembled custom light field displays, increasing production efficiency by 25 percent.

### RESEARCH

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#### NATIONAL ALLIANCE FOR WATER INNOVATION (NAWI), University of Cincinnati

*Research Assistant, August 2020 – August 2021*

- Conducting literature review on biological treatment technologies for removal of key contaminants from agricultural drainage water.
- Examining challenges of current treatment technologies and opportunities for improved nutrient, selenium, and salinity removal efficiencies.
- Collaborating with team, engaging in weekly meetings and communication, and delivering bi-weekly research updates on review of treatment technologies and reuse of agricultural drainage.

### TECHNICAL SKILLS

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- AutoCAD, ArcGIS, MATLAB, Python, LabVIEW, EPA Net, SWMM

## Jase Headings

Environmental Engineering

2222 Ravine St, Cincinnati, OH 45219 | headingjm@mail.uc.edu | (614) 674-1750

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### EDUCATION

#### The University of Cincinnati

05/23

Bachelor of Science; Environmental Engineering  
Cumulative GPA: 3.884

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### WORK EXPERIENCE

#### AquiSense Technologies – Erlanger, KY

01/22 - 09/22

##### *Applications Engineer*

- Managed more than a dozen custom projects, facilitating project planning, role designation, and status updates to meet client needs.
- Addressed and answered customer inquiries via phone and email.
- Scheduled, attended, and led in-person and virtual meetings with clients to discuss product inquiries and project development.
- Drafted, finalized, and presented reports and proposals for clients.

#### Calvary Industries Inc. - Fairfield, OH

01/20 - 08/21

##### *Quality Control/Reacher & Development Lab Technician*

- Presented research on problematic formulas and proposed corrections for future formulation.
- Enhanced organization and multitasking skills to approve up to 5 samples simultaneously.
- Completed over 100 lab reports through collaboration with coworkers and communicated results with customers.
- Conceptualized and finalized 1 new lab procedure using critical thinking and active research.
- Performed and perfected common lab techniques by testing and ensuring over 1000 samples complied with customer specifications.
- Conducted tests and learned equipment, including atomic adsorption spectroscopy, Fourier transform infrared spectroscopies, free/total alkalinity/acid titrations, kinematic & dynamic viscosities, specific gravity, etc.

#### Plain City Aquatic Center - Plain City, OH

05/16 - 08/19

##### *Assistant Manager*

- Communicated and oversaw schedule assignments for coworkers.
  - Managed daily chemical examination, result logging, and physical treatment of active pools to ensure the safety of patrons.
  - Performed backwash on large sand filters and replaced filter baskets for main and auxiliary pool.
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### COMMUNITY ENGAGEMENT

#### Bearcat Buddies - Cincinnati, OH

Winter 2018, Fall 2019, Spring 2021

- Educated youths of 3 local Cincinnati Schools by supporting academics and etiquette.
  - Inspired children to succeed inside and outside of school by being an example to follow.
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### INTERCOLLEGIATE ATHLETICS

#### The University of Cincinnati - Division 1 Track & Field

01/19 - 05/21

- Demonstrate time management by balancing schoolwork, practice, and competition.
- Exhibit hard work and dedication through continuation of athletics at the Division 1 Collegiate level.

# Request for Proposal

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## **Environmental Engineering Senior Capstone Project University of Cincinnati**

### **Storm Water Reuse at the Cincinnati Zoo and Botanical Garden**

**Sponsor: Cincinnati Zoo and Botanical Garden**

**August 2022**

#### **Introduction**

The Cincinnati Zoo and Botanical Garden (CZBG) is the second oldest Zoo in the United States and it will be 150 years old in 2025. In recognition of this milestone, the Zoo developed a master plan that reviewed all aspects of the Zoo including: existing animal habitats; new animal habitats; the future of several species as it relates to Zoo compatibility; and the “foot print” of the Zoo. The “foot print” of the Zoo for the purpose of this discussion consists of water and energy usage, solid waste management, and community relations. The focus of this RFP is on water usage and, in particular, supporting the goal of being “Net Zero” for water usage by 2025.

In the last ten years through maintenance, conservation, and new capital projects, water usage at the Zoo has reduced from nearly 300 million gallons a year to less than 50 million gallons a year. Since approximately 50 million gallons of storm water currently drain off the Zoo’s campus on an annual basis, it is feasible that the Zoo could become Net Zero water if the storm water is captured and re-used.

#### **Site Description**

The Zoo is located in a combined sewer overflow (CSO) drainage shed. When major storm events occur, the combined sewers back up into our neighbor’s basements, which is a major public health issue in lower income communities such as Avondale. The attached drawing shows the various storm water sheds at CZBG. Storm water currently leaves the campus at seven different locations.

Storm water from the Africa exhibit is currently collected in a 450,000 gallon tank. The water is then treated and stored prior to re-use for moat filling, animal holding spray down, and irrigation. The stormwater at Entry Village percolates into the ground using a 3 ft deep gravel layer under pervious pavers. The Roo Valley project, which was complete in the spring of 2020, has a system similar to the Africa exhibit. The Elephant Trek project, to be completed in 2024, will be able to store roughly 1,000,000 gallons using the many lessons learned from prior projects.

#### **Project Goal**

The goal of this project is to collect as much storm water as possible from the roughly 58-acre campus, thus reducing sewer backups in our neighbor’s basements. We intend to reuse the reclaimed storm water for toilet flushing, habitat and holding spray down, moats, and irrigation. We do not intend to reuse the reclaimed storm water for sinks, drinking water, food preparation, or related cleaning activities.

Specifically, the area of focus for this project is the area shaded red, known as the Jungle Trails Watershed Area. It is a challenging area of the zoo topographically, and finding creative ways to store, clean, and redistribute this water will be the task at hand. There are several major capital projects slated to be completed in this zone over the next 5 years, so the goal is to incorporate storm water collection and reuse solutions into those capital projects.

### **Description of Services Required**

The student consultant team will conduct a thorough review of the existing CZBG storm water re-use systems, review options for separating the existing storm and sanitary sewer collection systems, review options for storm water pre-treatment, review options for storm water storage, review options for storm water treatment, and review potential regulatory hurdles for re-using storm water in Cincinnati. Upon completion of the initial report and approval from CZBG, the student consultant team will develop conceptual drawings of their recommended system.

CZBG and their engineering consultant, IBI Group, will coordinate closely with the student consultant team throughout this project and they will provide access to CAD, data, etc. that is required to ensure project success.

### **Deliverables**

During the Fall Semester, the student consultant team should complete the following tasks:

- Conduct a site visit to the Zoo;
- Conduct a technological review of existing data;
- Conduct literature searches and review similar projects;
- Conduct literature searches for grey and green infrastructure solutions;
- Conduct a review of the existing storm water collection system;
- Develop a sanitary and storm water separation approach for existing buildings;
- Review options for treatment and storage;
- Review options for pre-treatment;
- Review potential regulatory hurdles for re-using storm water in Cincinnati;
- Conduct alternative analyses for all processes evaluated;
- Meet with CZBG and IBI Group as needed;
- Prepare a project proposal on key findings and recommended options; and
- Provide a present on the proposed options to CZBG and IBI.

During the Spring Semester, the consultant team should complete the following tasks:

- Develop conceptual design drawings of the recommended reuse options;
- Conduct a thorough economic analysis of the recommended reuse options, including energy costs and savings derived from lower MSD charges;
- Identify the infrastructure changes required to support deployment of the reuse options;
- Prepare a final report that includes all tasks from the Fall Semester and Spring Semester; and
- Provide an oral presentation of key findings at the end of the semester.

Map of the drainage areas at the zoo where the Jungle Trails watershed area is shaded in red.

