UBC Rainwater Capture and Reuse

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Acknowledgments

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Executive Summary

Capstone group 4 was tasked with designing a system to mitigate flood risks, improve rainwater quality, as well as reuse it for practical applications.

This report outlines a fully designed rainwater collection and treatment system at the University of British Columbia, and the steps taken to reach the design. With an annual rainfall amount of approximately 5 billion liters, models were created to simulate storm conditions for a 100-year event. With these parameters in mind, the designed system includes five main components: Rainwater detention, sand filters, cisterns, bag filters, and UV disinfection. In combination with each other, they provide storage, filtration, and disinfection to meet potable treatment standards. The specifications of each component will be included in this document.

For this system to be built and integrated, it was estimated that a total capital cost (CAPEX) would be $3.4 M CAD, and an estimated annual operational expenditure (OPEX) of $90,000 CAD. This system does not generate revenue and therefore does not have a payback period. Through an environmental assessment, it was determined that there would be a net positive impact due to reduced runoff and ecosystem growth. A hazard and risk assessment were conducted as well to identify and mitigate any potential problems. To fully integrate the design, a commissioning and startup plan was also created, outlining a plan for installation, construction, testing, and handover.

This document includes a comprehensive overview of project engineering, design basis, stakeholder engagement, engineering drawings and justification, calculations, hazards, environmental, and economic assessments, as well as a commissioning and startup plan.

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5 List of Abbreviations

BMP	Best Management Practice
CAPEX	Capital Expenditure
CEPA	Canadian Environmental Protection Act
CCME	Canadian Council of Ministers of the Environment
CMIP6	Coupled Model Intercomparison Project Phase 6
CPP	Campus and Community Planning
EMA	Environment Management Act
EWS	UBC Energy and Water Services
GCM	Global Climate Models
GEV	Generalized Extreme Value
GIS	Geographic Information System
HADD	Harmful Alteration, Disruption, or Destruction
IDF	Intensity-Duration-Frequency
ISMP	Integrated Stormwater Management Plan
OPEX	Operating Expenditure
PM	Particulate Matter
PPE	Personal Protective Equipment
PCSWMM	Personal Computer Stormwater Management Model
SEEDS	Social Ecological Economic Development Studies
SSP5-8.5	Shared Socio-Economic Pathway 5-8.5
SWMM	Stormwater Management Model
TPO	Temporary Protection Orders

TSS	Total Suspended Solids
UBC	University of British Columbia
WSA	Water Sustainability Act
WQI	Water Quality Index

6 Introduction

Founded in 1908, the University of British Columbia (UBC) serves as a learning ground for tens of thousands of students every year. It is a world leader in developing sustainable infrastructure and low-impact projects, with a vision of several ideas for a more sustainable future. Located on the University Endowment Lands west of Vancouver, it has a population of approximately 60,000 students and 18,000 faculty and staff members, as well as community members who live in the area [1]. It has an area of approximately 414 ha and receives approximately 5 billion L of rain annually [2]. Currently, UBC's stormwater infrastructure consists of several catchments from drains, channels, and rain gardens through which rain is collected and released from outfalls into the ocean [3]. Future UBC projects are moving towards more sustainable solutions while also carrying out their climate plan for zero net emissions by 2030 [4].

The existing stormwater infrastructure at UBC consists of four main catchment areas and five discharge points at the west, south, and southeast bounds of the campus. Considering UBC's newer development plans, the total impervious area is projected to increase. As such, the probability and severity of erosion and flooding is becoming an increasing risk in the near future. Four main flood-prone locations on UBC campus were identified on the 2017 Integrated Stormwater Management Plan (ISMP). This is highlighted in Figure 1 below [5].

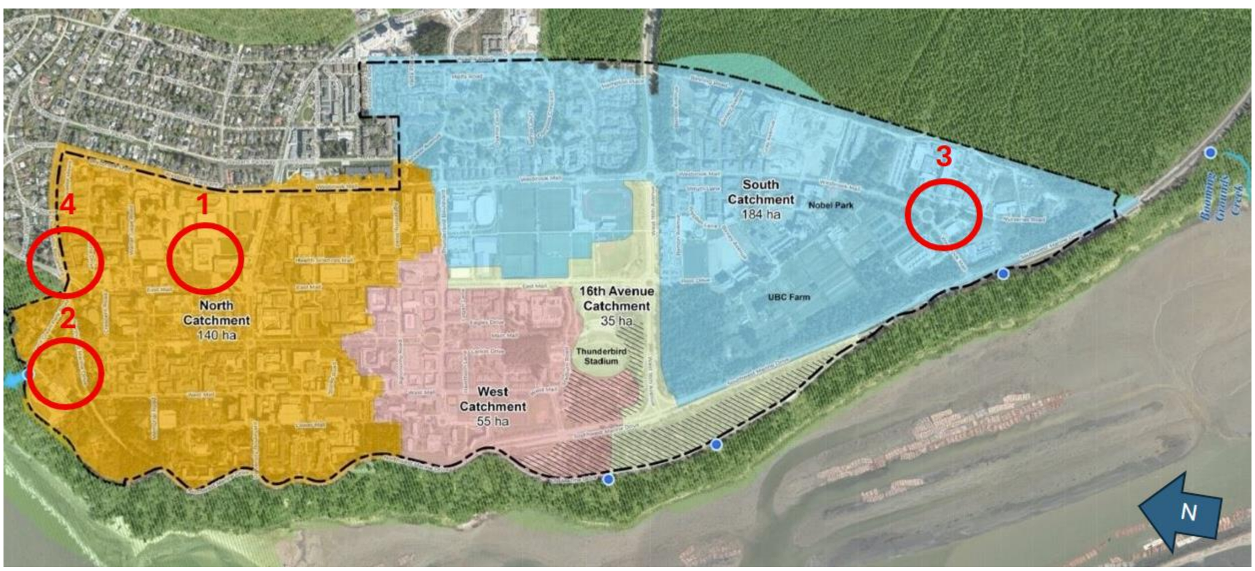

Figure 1: Flood-prone locations identified on UBC Campus

This project aims to upgrade a key area of the stormwater management system on the UBC Vancouver campus, specifically one of the flood prone locations located in the north catchment area. The north catchment was chosen due to having the most flood prone locations as seen in Figure 1 (Locations 1, 2, 4) and implementing a single design would have the most downstream benefits.

The project objectives include mitigating flood risks and capturing and reusing rainwater for practical applications. The final design will consider future climate conditions and ensure compliance with regulatory requirements to create resilience for the campus' stormwater management for years to come.

Figure 2 depicts the battery limits for the project. It is important to note the exclusion of water reuse from the battery limits; this would be a separate project to connect the treated collected water for reuse with existing water infrastructure. The collection of water, rainwater detention, storage, and treatment are all included in the battery limits. This includes factors such as waste management and energy usage.

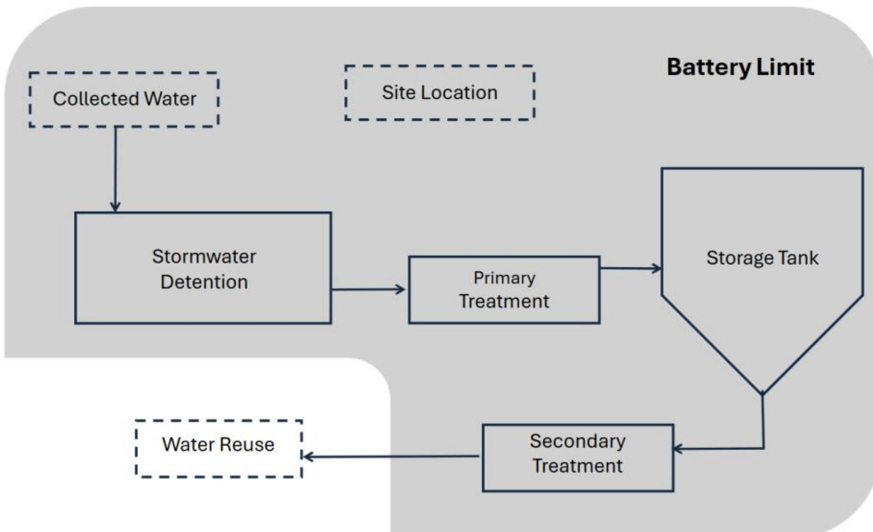

Figure 2: Battery Limits

7 Project Engineering

The timeline and deliverables submitted throughout the year are outlined in Table 1. Key deliverables included the Proposal, Design Basis Memorandum (DBM), Progress Report, Detailed DBM, Impacts & Stakeholder Engagement, Design & Innovation Day Poster, and Final Report. Note that some months did not include a deliverable submission, but the time was spent researching and preparing for the next document.

Table 1: Submitted deliverables for each month

Month	Deliverable
September	N/A
October	Proposal
November	DBM
December	Progress Report
January	Detailed DBM
February	Impacts & Stakeholder Engagement Plan
March	N/A
April	Poster and Final Report

The design procedure started with identifying the problem statement, as well as understanding the project's objective and scope. Thereafter, Group 4 was able to compose a project proposal which highlighted the need for the design. Next, the DBM was put together which included considerations for specification requirements, codes and legislation, climate conditions, as well as stakeholder commitments. The progress report outlined updates on the design basis and scope, and included design options such as detention ponds, cisterns, and potential treatment systems. With design options in mind, the options were weighed, and the finalized system was determined in the detailed DBM along with more specific requirements for each component. Finally, an impacts assessment and stakeholder engagement plan were created to account for the economics of the project, as well as safety and environmental considerations. With each of those deliverables completed, a poster was created to outline the finalized design as well as the economics of it.

Table 2 2 shows the estimated person-hours for each deliverable, resulting in a total of approximately 960 hours throughout the development of the project. Some deliverables had a presentation associated with them. In those cases, the number of person-hours for the presentation were included. Notably, the detailed DBM took the most hours because a significant amount of time was spent researching and compiling data. It was also an important document because it would solidify the foundation of the rest of the project.

Table 2: Project hours summary

Deliverable	Number of Person-Hours
Proposal	140
DBM	140
Progress Report	80
Detailed DBM	220
Impacts & Stakeholder Engagement	80
Poster	80
Final Report	220
Total	960

To ensure the contents of each deliverable were accurate, the team implemented quality control measures. Each member was assigned a section of each deliverable to review and provide feedback on. After the feedback and comments were complete, each section was revised to create the final deliverable.

8 Design Basis and Stakeholders

8.1 Design Basis Overview

The proposed design has 5 main steps: detention, sand filtration, cistern storage, bag filtration, and UV disinfection as shown below in the system diagram below in Figure 3. As the collected rainwater is already of high quality, pre-treatment, such as first flush diversion, was deemed unnecessary. The rainwater will be collected from the three adjacent roofs into a detention pond where native flora and fauna will flourish while also assisting in treating the rainwater. Primary treatment will occur via rapid sand filtration. The rainwater will then be stored in above ground concrete cisterns. When water is needed by the end-use, the water will be released from the cisterns through the bag filter and UV disinfection, of which it'll finally reach its end-use in IKB.

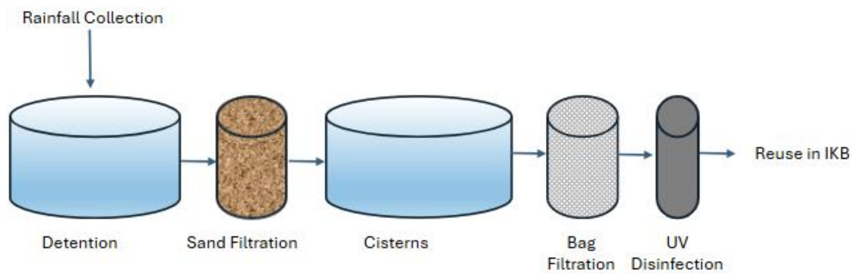

Figure 3: Final System Diagram

Through the 7 months of continuous work on this project, a Design Basis Memorandum (DBM) and a Detailed Design Basis Memorandum was created of which all consequent work was based on. The general DBM was submitted as *DBM final* on November 10,2024 while the detailed DBM was submitted as *Detailed DBM Final* on February 12, 2025. The general DBM focused primarily on the general technical basis, stormwater management, and climatic conditions whereas the detailed DBM zeroed in on the system itself; equipment, hydraulic structures, and nature-based designs. The basis established in the general DBM was followed closely throughout the entire lifespan of the project. Initially, the water was not going to be treated to drinking water quality since the initial design prompted for reuse for toilet flushing. However, after recognizing the high quality of the collected rainwater and its high availability, it was decided that the water will be treated to drinking water standards to be used for multiple purposes in IKB such as water fountains, irrigation, and toilet flushing. Due to it being treated to such high standards, it can easily be scalable with additional reuse purposes in other potential buildings such as the newly constructed Rec North building or even other projects down the line. By carefully following the design basis created and making slight changes when necessary, the final system was created.

8.2 Stakeholders

There are eight key stakeholders involved with this project, and an overview of them is listed below.

- UBC Campus & Community Planning, or more specifically the Sustainability and Engineering team, is responsible for the development of the campus and the communities surrounding it.
- The Social Ecological Economic Development Studies Sustainability Program, or SEEDS, is a program that aims to employ the campus as a living laboratory to create research opportunities and interdisciplinary partnerships to allow for the advancement of UBC's sustainability program.
- UBC Energy & Water Services is responsible for the generation and distribution of utilities on campus and aims to conserve these resources and reduce environmental impacts through mindful stewardship.
- The students and faculty on campus are key stakeholders as the space is used daily.
- UBC Administration plays a critical role in overseeing campus operations, policies, and long-term planning.

- Residents of the UEL are external stakeholders. Though not a part of the university, these residents are directly affected by campus developments and sustainability initiatives.
- The general public, including visitors to UBC of which many are prospective students, experience the campus through its architecture, natural spaces, and sustainability initiatives.
- The Musqueam and other local Indigenous Nations act as key partners and rightsholders. With extensive cultural knowledge and perspectives on land, water, and sustainability, a partnership must be established to ensure respectful collaboration to achieve UBC's sustainability initiatives.

Further details can be seen in the Impacts & Stakeholder Engagement Plan submitted on the 6th of March, 2025.

8.3 Climate Change Considerations

With one of the key objectives being to reduce the risk of flooding on campus, this project goes hand in hand with climate change. As climate change intensifies, so does rainfall. Therefore, the team decided the proposed design will be designed for a 100-year storm event under climate change conditions since that is when the largest storm event occurs. By designing for the largest foreseeable storm, it will help mitigate flood risks while simultaneously providing potable water for reuse during the dry summer months. In addition, the materials for each component were chosen with climate change in mind. Everything is designed to be durable and able to withstand the design life of the system.

8.4 Resources, Databases, and Tools

Several tools were utilized throughout to aid in the design of the system. The most valuable resource within the first couple weeks was undoubtedly the ISMP in 2017 [5]. It allowed the team to get a better grasp on the problem statement of improving stormwater management on campus to mitigate flood risks on top of capture and reuse for various uses. In the initial conceptualization phase, several databases such as the IDF_CC tool and other weather station databases [6]. The IDF_CC tool is an intensity-duration-frequency tool developed by the University of Western Ontario adapted to climate change which makes it a perfect fit for this project. An additional key data source utilized was the Government of Canada's past weather and climate database. These databases worked in tandem with climate records provided by SEEDS and UBC Campus & Community Planning. In addition, GIS and infrastructure maps were used during preliminary design for storm mains and other key infrastructure. As the system is designed for reuse in IKB, the library's water use data was employed to gauge the amount of water required annually. PCSWMM was utilized throughout for the design and sizing of major components such as the detention pond and the cisterns. Another key software used was AutoCAD. It was utilized for the creation of site layouts; both plan and profile views. Finally, the entire Microsoft Suite was employed. Microsoft Word for report writing, Microsoft PowerPoint for presentations and posters, Microsoft Visio for the process flow diagram and other diagrams, and finally Microsoft Excel for various tasks.

A list of the key resources can be observed below:

- ISMP2017
- UBC Technical Guidelines
- IKB Water Usage Data
- UBC GIS data
- UBC Infrastructure maps

Some of the software used are listed below:

- PCSWMM
- QGIS
- Microsoft Suite
- AutoCAD

9 Engineering Drawings and Design Narrative

9.1 System Justification

Figure 4 shows the overall design layout for this project, with a detailed full-sized drawing provided in Appendix A and an expanded map figure included in Appendix A. The configuration was guided by the setback requirements and specifications detailed in the Detailed Design Basis Memorandum (February, 2025) in Appendix A.

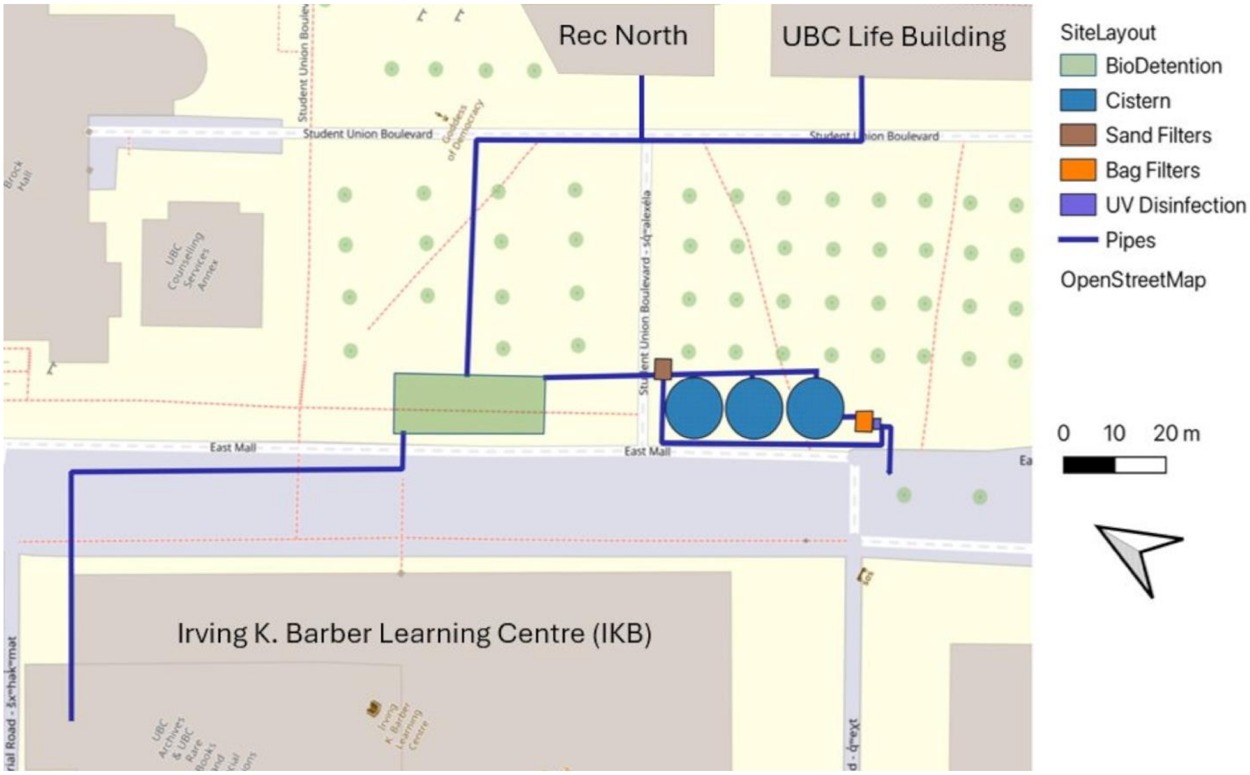

Figure 4: Map Overlay Site Layout

The final system is designed in the North Campus between IKB and the newly constructed Rec North. The area is currently adjacent to forested space, commonly used by students and faculty as a footpath. Due to its proximity to flood prone location #1 as mentioned in Figure 1, the team decided it would be appropriate to choose it for our project location. It is also within close proximity of IKB, Rec North, and the LIFE Building, all of which have large roof areas the system can collect rainwater from.

The plan view of the site layout can be observed in Appendix A. The positioning of each component was decided on waterflow, infrastructure, and disturbance to the ecosystem. The positioning and spacing of each individual component were decided through consultation with the UBC Technical Guidelines [7].

9.2 Biodetention Justification

The biodetention system serves the rainwater reduction component of the design through detaining the water during storm events. By using this detention facility, the subsequent treatment and cistern components are relieved from matching peak inflow rates during storm events. The biodetention system temporarily detains water, allowing controlled release to the treatment system and cisterns, matching with actual water usage rates in IKB.

The biodetention pond was specifically sized to accommodate the total runoff from roof catchments during a 100-year climate change storm event, as the roof catchments' 100%

impervious surfaces contributing significantly to stormwater runoff. Additionally, designing for such a substantial event ensures the pond's adaptability for capturing stormwater from expanded sources in the future. The pond's dimensions are 15 meters by 30 meters, with a total depth of 2 meters—half underground and half above ground bounded by concrete walls. A sectional drawing of the pond can be seen in Figure 5 and a detained drawing is in Appendix A. It has a capacity of approximately 1,000 cubic meters, meeting the recommended upstream detention volume near the North Campus Spiral Drain as identified in the 2017 ISMP [5].

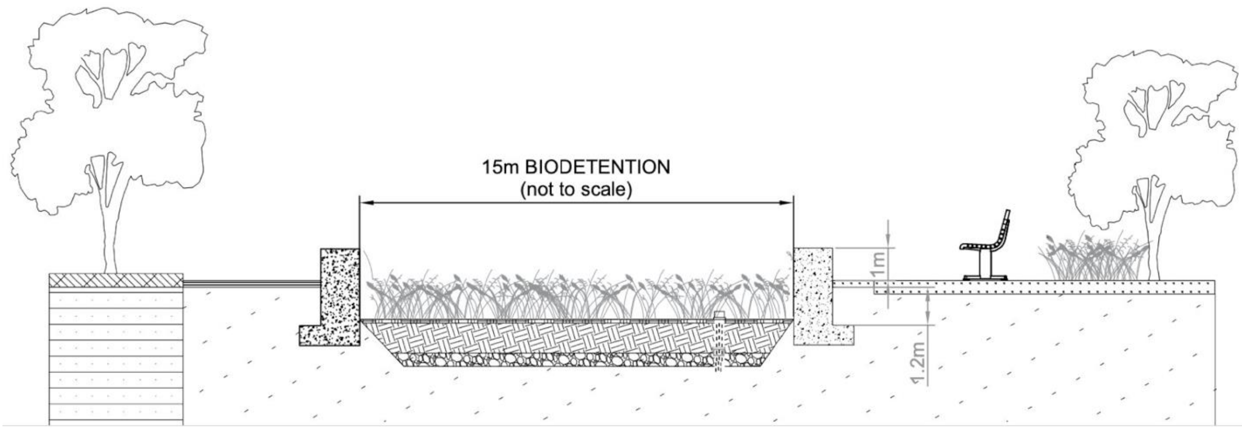

Figure 5: Biodetention Sectional Drawing

It is advised that Campus and Community Planning consult with the Musqueam community to incorporate indigenous knowledge into plant selection, ensuring ecological health and cultural relevance.

9.2.1 Cisterns

The cisterns are designed as a functional and visually engaging component for the system. The primary purpose is for storage of rainwater during the wet winter months for reuse during the dry summer season, alleviating demand on municipal water supplies. Three large concrete cisterns 15m in height and 10m in diameter work in parallel to ensure constant uptime. The dimensions abide by a H:D of 1.5:1 for optimal performance [8]. A total of three cisterns were selected to be utilized as it is unrealistic to have one massive cistern due to loading concerns and overall footprint. It was also unfeasible to have multiple smaller cisterns as maintenance and upkeep would be challenging. Each individual cistern has a capacity of 1178 m^3 for a combined volume of 3534 m^3.

Some additional components are also required for proper operation; these include an overflow pipe, reinforced concrete pad, internal copper lining and ventilation to prevent microbial growth. The overflow pipe will be used alongside proper headspace within the cistern to prevent the cistern from being full which may cause it to potentially burst with the immense pressure from the stored water. A reinforced concrete pad will be implemented for structural support to account for it holding vast amounts of water.

Copper lining has been shown to have antimicrobial properties [9]. This, coupled with ventilation on the roof of the cistern, will lead to negligible microbial activities within the cistern.

For the cistern to blend seamlessly with the surrounding infrastructure, close and careful consultation will be conducted with the Musqueam First Nation to request artwork. In addition to artwork, educational signage will be implemented to improve the aesthetic appeal.

9.2.2 Treatment

After the rainwater has been collected from the nearby rooftops and passes through the detention pond, the rainwater will flow through a series of treatment processes that meet the BC 43210 Drinking Water Objectives [10]. The objectives are listed as follows:

- 4 log inactivation of viruses
- 3 log removal or inactivation of Giardia Lamblia and Cryptosporidium
- 2 barriers or treatment processes
- <1 NTU of turbidity with a target of 0.1 NTU
- 0 E. Coli or total coliforms

The initial step of treatment will be flowing through two gravity driven sand filters set up in parallel. This will act as the primary treatment that physically removes any solids, indicated by turbidity and total suspended solids (TSS), present within the water. Following that, it will be sent to the cisterns for storage.

Once in need, the stored water will be released and flow through a 5-micron bag filter. This will act as a protective measure prior to the UV reactors against any finer solids that were not screened out in the prior stages. The rainwater will then be sent through a flow through UV disinfection system, inactivating all microorganisms of up to 4-log removal. The then captured rainwater is now treated to potable water standards, ready to service the IKB Learning Centre water demands. Each treatment component will have an additional unit for contingency, with the total being three sand filters (two operational at a time), two bag filters, and two UV disinfection systems.

A block flow diagram of the treatment components and their target removals are illustrated in Figure 6.

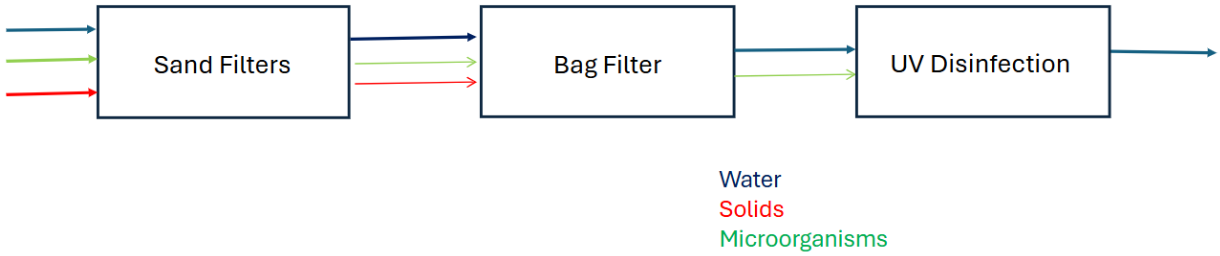

Figure 6: Block Flow Diagram of Treatment Components & Target Removals

9.3 Process Flow Diagram and Control Narrative

The process flow diagram can be found in Appendix A, and it outlines how water flows through all the equipment in the system.

Water flows into the detention pond from the rooftop collections – water from Irving K. Barber, LIFE Building, and the newly constructed Rec North Building. All water will go into the detention tank and falls over weir if water is full. The height of the weir is 0.3 m from the top of the detention pond.

Water must leave the detention pond within 48 hours. It does so in two possible ways:

1. Water sent from detention to cistern with pump
2. Water flows from detention to sewer

The pump turns on and sends water to the cistern if the cistern's water level is <14 m and the detention water level is > 0.6 m. The pump turns off when the water level in the cistern is >14.5 m.

These scenarios are summarized in Table 3 below.

Table 3: Water levels for control systems

Pump	Water level in detention tank	Water level in cistern
On	> 0.6 m	< 14 m
Off	> 0.6 m	> 14.5 m

Water leaves the cistern as there is water demand.

10 Engineering Calculations and Deliverables

10.1 Rainwater Modelling

10.1.1 Design Storms

Current Storm Conditions:

The rainfall data for the current storm conditions was sourced from the IDF_CC 7.0 tool, which was cross-referenced with the UBC's rain gauge data. The IDF_CC tool 7.0 uses historical data from the Vancouver UBC Station which has 33 years of data. The tool can create IDF curves using both generalized extreme value (GEV) and Gumbel distributions. Additional precipitation data from UBC from 1994 to 2023 showed a minimum 24-hour rainfall of 88.8 mm. The most comparable storm on the IDF_CC Tool would be the 25-year 24-hour storm which has a total precipitation of 96 mm seen in. Since the IDF_CC tool yields a greater precipitation, it gives more conservative rainfall estimates so it will serve as the basis for the storms in the design. Table 4 below show the IDF curves that will be used in the modeling and design process [11].

Table 4: Current Conditions IDF Curve: Intensity (mm/hr)

	2 Year	5 Year	10 Year	20 Year	25 Year	50 Year	100 Year
5 min	32.23	46.26	57.62	70.39	74.88	90.15	107.79
10 min	24.25	34.31	41.86	49.86	52.56	61.44	71.12
15 min	20.17	28.01	33.78	39.77	41.78	48.28	55.25
30 min	13.89	18.66	22.06	25.53	26.67	30.33	34.16
1 h	9.36	12.1	14.35	16.89	17.78	20.84	24.4
2 h	6.71	8.03	9.02	10.08	10.44	11.62	12.91
6 h	4.4	5.21	5.75	6.26	6.43	6.93	7.43
12 h	3.36	4.17	4.7	5.2	5.36	5.86	6.35
24 h	2.27	2.89	3.35	3.85	4.02	4.57	5.17

Future Storm Conditions

The rainfall data used was also sourced from the IDF_CC Tool 7.0, which incorporates climate change scenarios developed by the Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models (GCMs). These scenarios can be simulated using both GEV and Gumbel distributions; however, a comparison of the two indicates that the GEV distribution is a more conservative estimate, so it will be used to create climate change design storms. The comparison between the two distributions can be found in Appendix X. The specific CMIP6 scenario selected for this analysis is Shared Socio-Economic Pathway 5-8.5 (SSP5-8.5), representing the scenario of no action taken to mitigate climate change which represents the worst-case scenario [11]. The IDF curves generated from this scenario are summarized in

Table 5, which will be used to make the model climate change storms.

Table 5: Climate Change IDF Curve: Intensity (mm/hr)

	2 Year	5 Year	10 Year	20 Year	25 Year	50 Year	100 Year

5 min	39.57	57.1	71.2	87.38	93.09	112.45	134.49
10 min	29.76	42.46	52.14	62.91	66.17	77.63	90.5
15 min	24.74	34.69	42.17	50.3	52.71	61.31	70.46
30 min	17.03	23.12	27.62	32.28	33.75	38.46	43.5
1 h	11.47	14.93	17.76	21.09	22.26	26.12	30.41
2 h	8.22	9.92	11.26	12.72	13.18	14.71	16.41
6 h	5.39	6.46	7.23	8	8.26	8.92	9.45
12 h	4.12	5.17	5.91	6.65	6.89	7.53	8.12
24 h	2.78	3.57	4.18	4.86	5.07	5.79	6.59

10.1.2 Current Conditions Model

The current conditions model was created using GIS data given by UBC, and imported into PCSWMM.

Figure 7 shows a map of the current UBC north catchment infrastructure, and Figure 8 gives the legend for each of the features.

The storm main and manhole GIS data was provided by UBC to use for modeling and general infrastructure information. For modeling the current conditions of the UBC North catchment, the GIS data was simplified to only include arterial mains on campus. All mains with a 0 invert were adjusted using the PCSWMM tool “Align Conduit Crowns” which adjusts the inverts to be similar in slope to conduits downstream. Any storm mains that were missing manholes were assigned a new manhole created by the PCSWMM “Auto-Connect” tool.

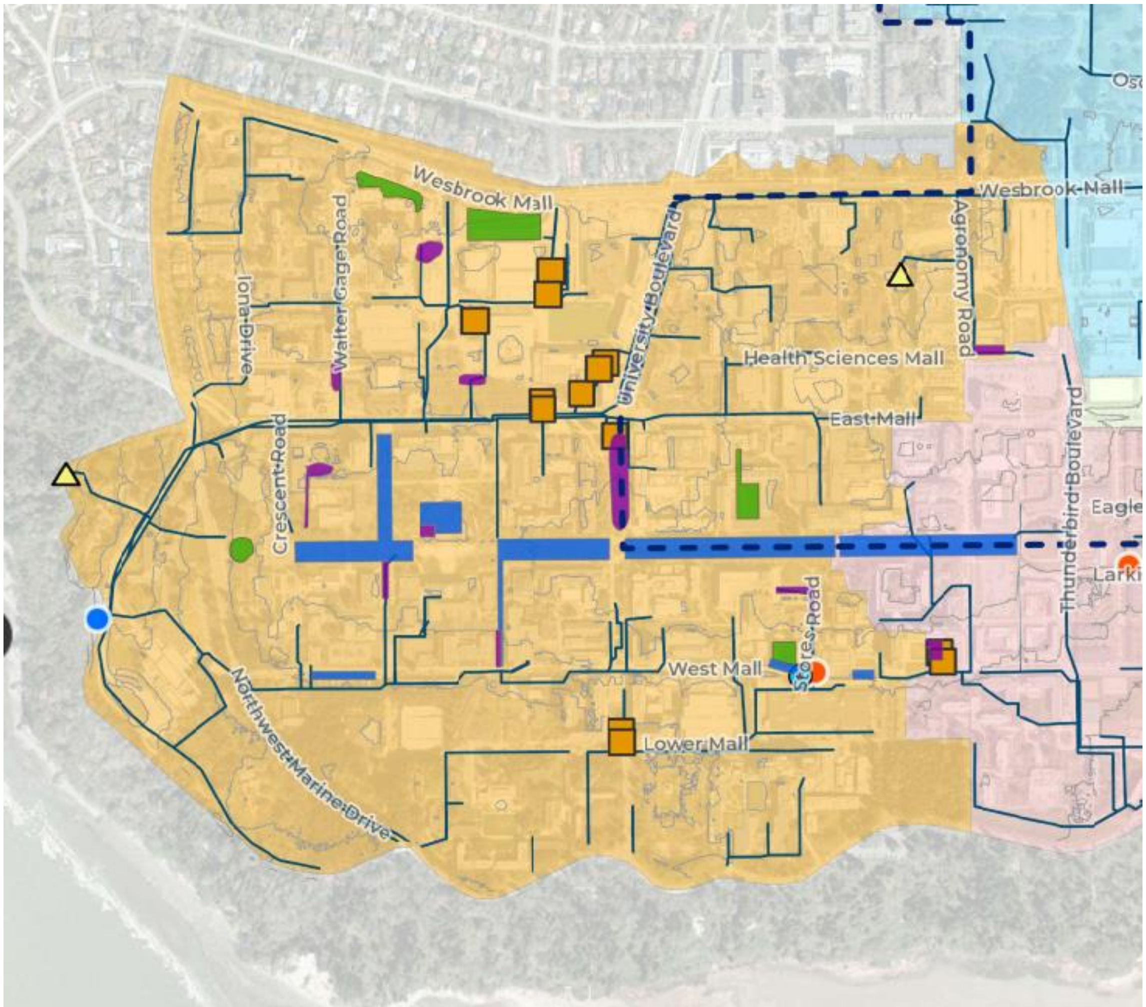

Figure 7: Current UBC North Catchment Infrastructure

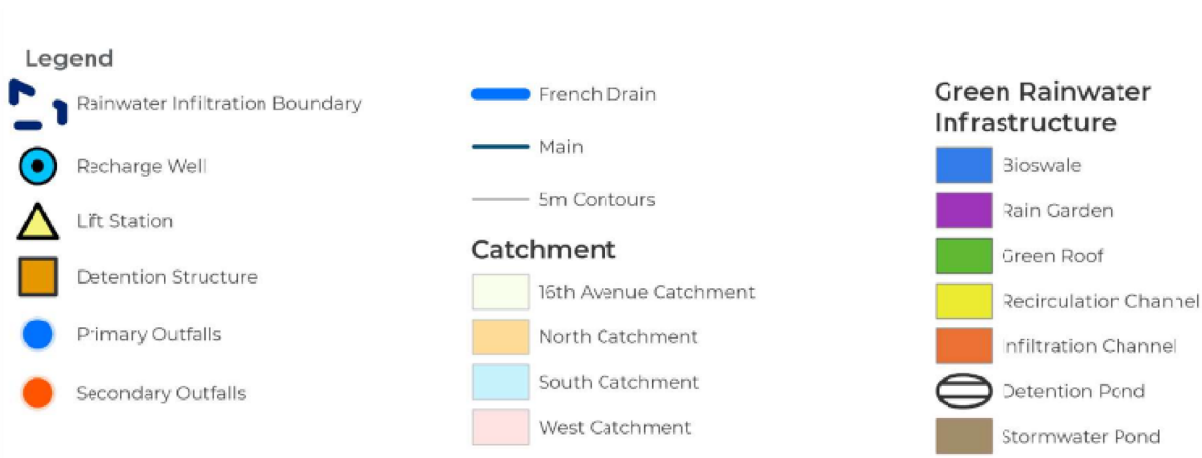

Figure 8: Legend of UBC Storm Infrastructure

10.1.3 Post-Development Conditions Model

Adjustments in the post-development model were only to the project area, focusing on introducing new conveyance routes to the detention pond and adding the pond itself near the existing storm manhole designated for overflow. This modified configuration is detailed in Figure 9, showing proposed storm mains (in light green) facilitating conveyance of rainwater from roofs directly to the biodetention pond.

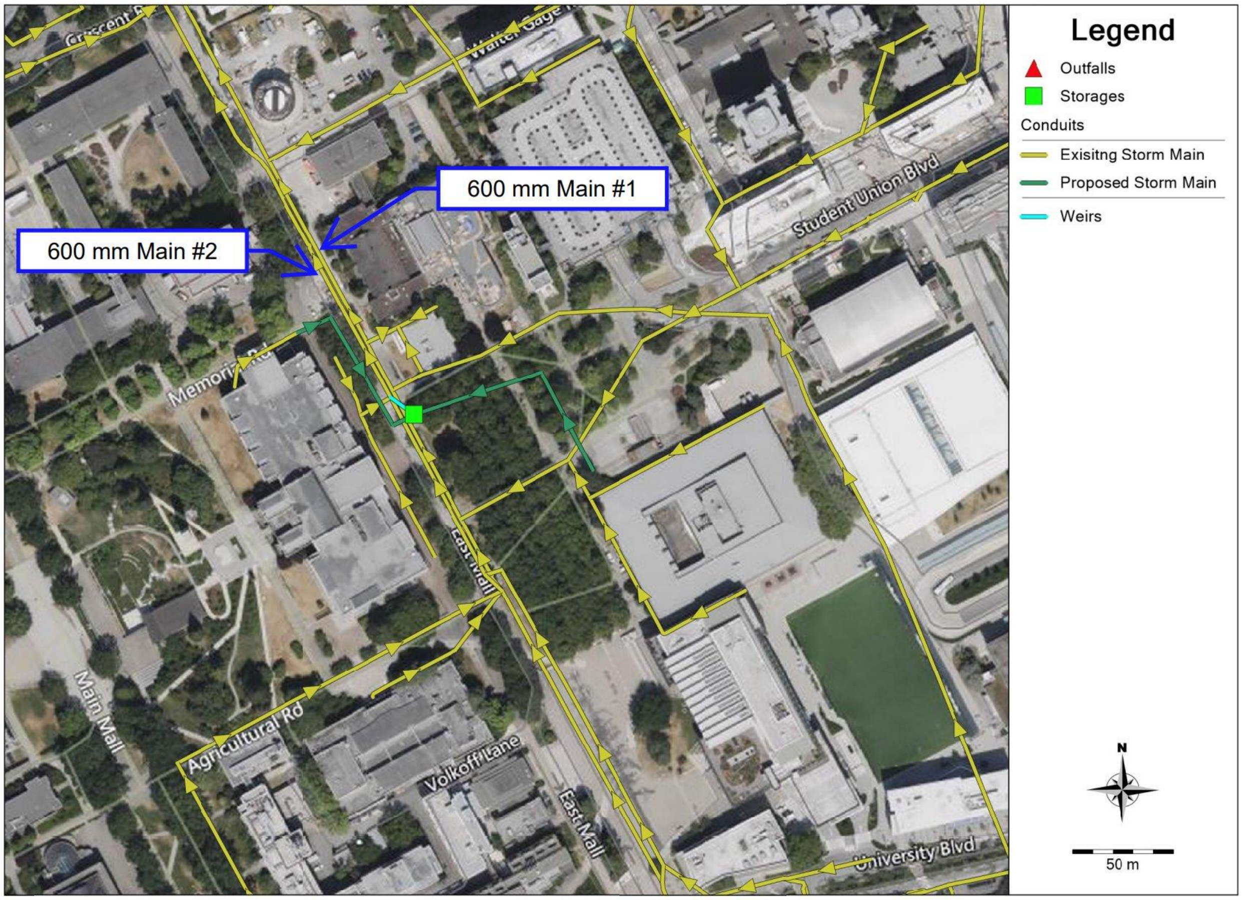

Figure 9: Post-Development Model Layout

An overflow weir was installed at the biodetention storage node for managing events exceeding the 100-year storm scenario which is 0.3 meters high and 0.75 m high with side slopes of 4:1. The primary mains, labeled Main #1 and Main #2 in Figure 9, currently service larger catchment areas of 28 hectares and 39 hectares, respectively. The proposed conveyance mains sized using PCSWMM are each 450 mm in diameter, ensuring no surcharging during the critical 100-year storm. The detention pond's critical sizing was determined by the 100-year 12-hour storm event scenario within PCSWMM, with dimensions of 15 meters by 30 meters with 2-meter depth and 2:1 side slope. This is a total volume of 900 cubic meters.

10.1.4 Model Results

Model outputs for the two storm mains, described earlier in Section 10.1.3, are summarized in Figure 10 and Figure 11. The comparison between pre-development and post-development peak flows during a 10-year storm event indicates reductions for flood mitigation and increased main capacity.

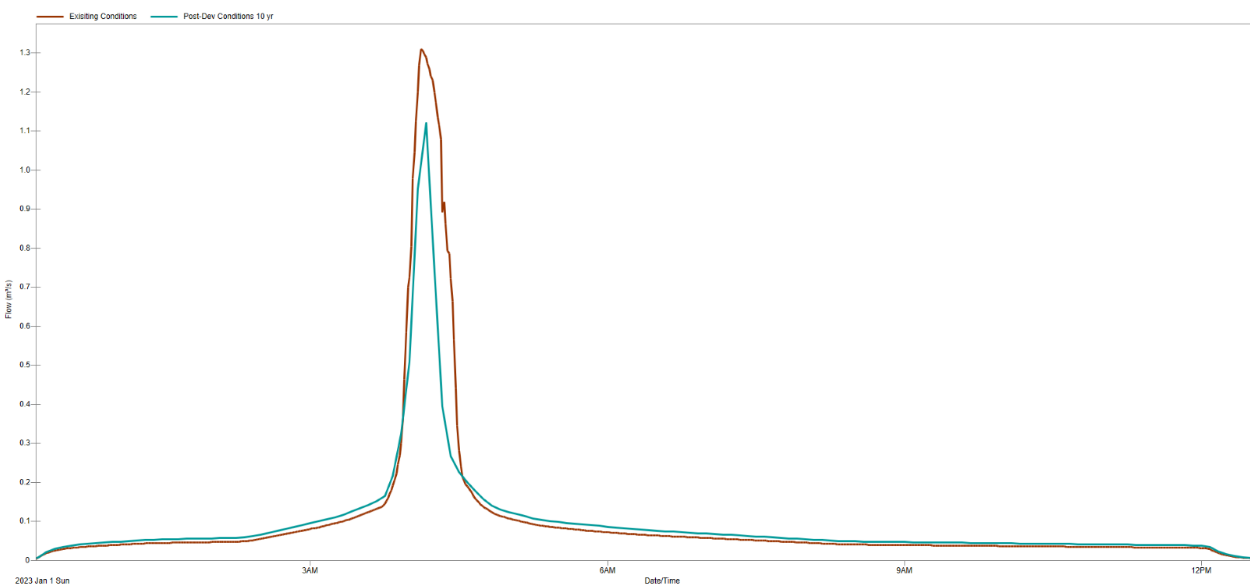

Figure 10: Main #1 10-Year Storm Event Results

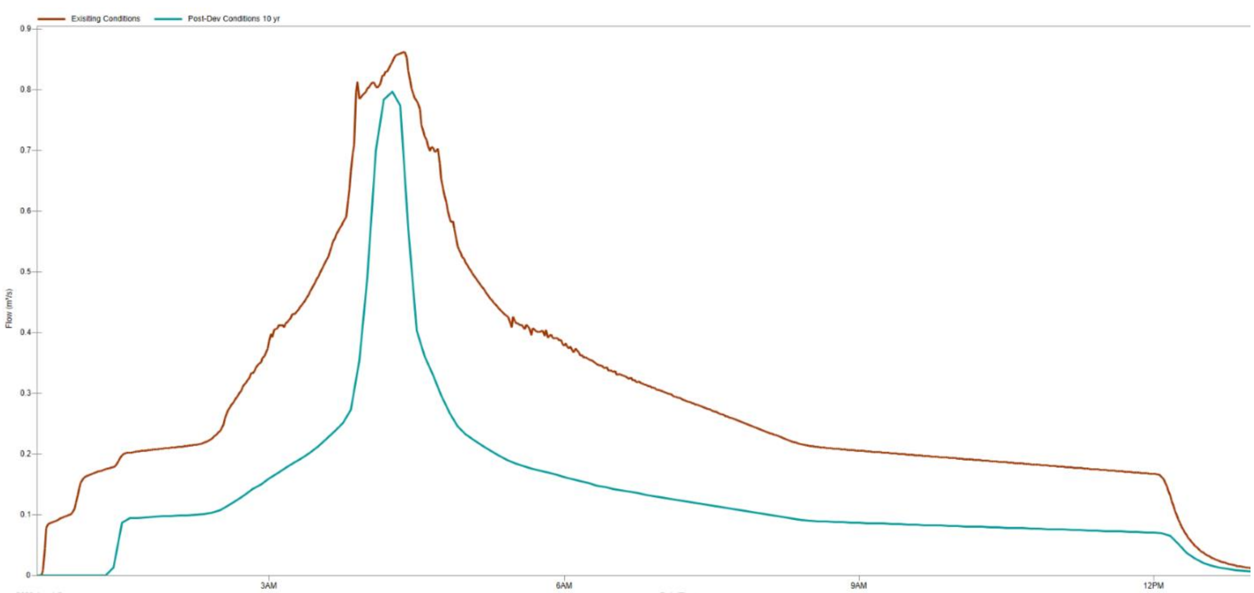

Figure 11: Main #2 10-year Storm Event Results

Results for the 100-year storm event (Figure 12 and Figure 13) exhibit no significant reduction in peak flow, attributed primarily to the pipes reaching full capacity due to their substantial catchment areas.

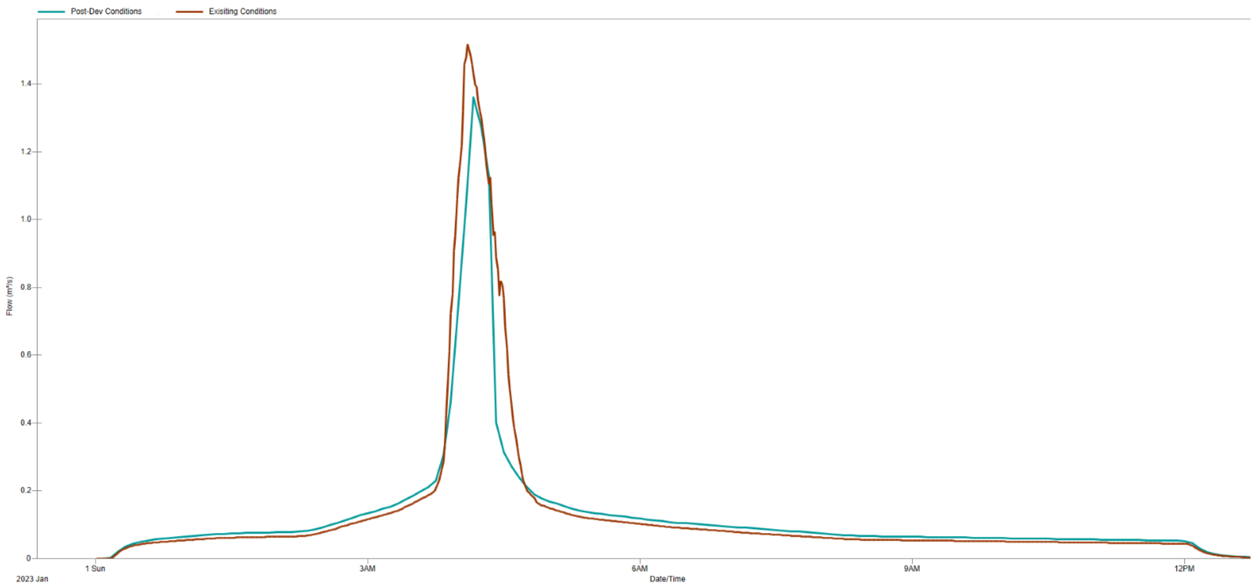

Figure 12: Main #1 100-year Storm Event Results

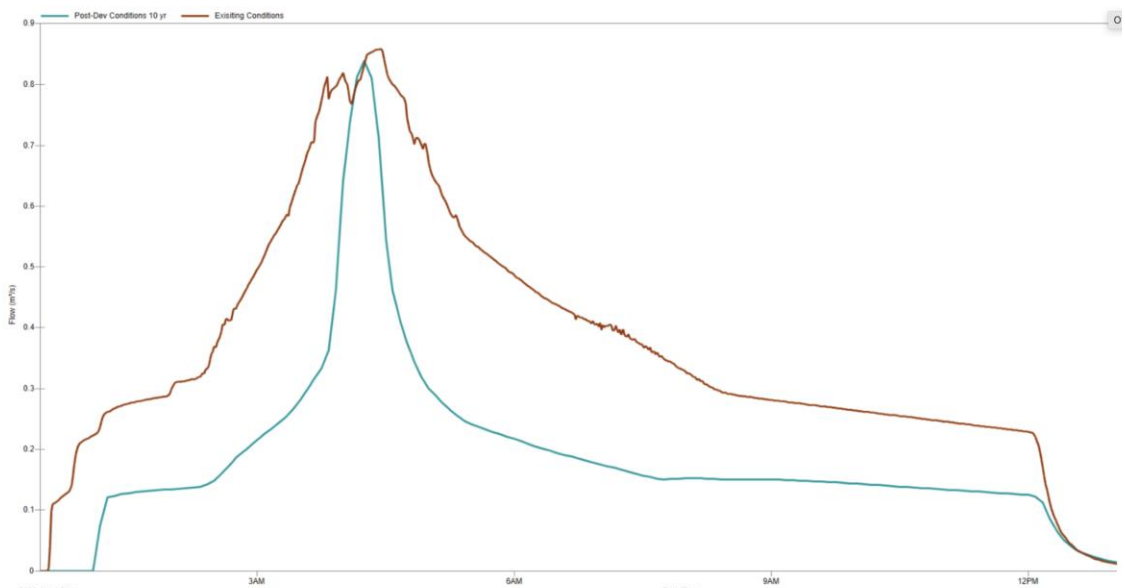

Figure 13: Main #2 100-year Storm Event Results

10.2 Water Balance

10.2.1 General Water Balance

The project's water balance analysis used historical daily precipitation records (2015 to 2023) from UBC and water usage data form 2023 sourced from SkySpark [12]. The combined catchment area of the IKB, Life Building, and SCR North buildings totals 17,588 square meters, assuming a roof water collection efficiency of 85%. The resultant water balance for all three roofs is depicted in Figure 14. In this figure, the y-axis represents the volume in cubic meters.

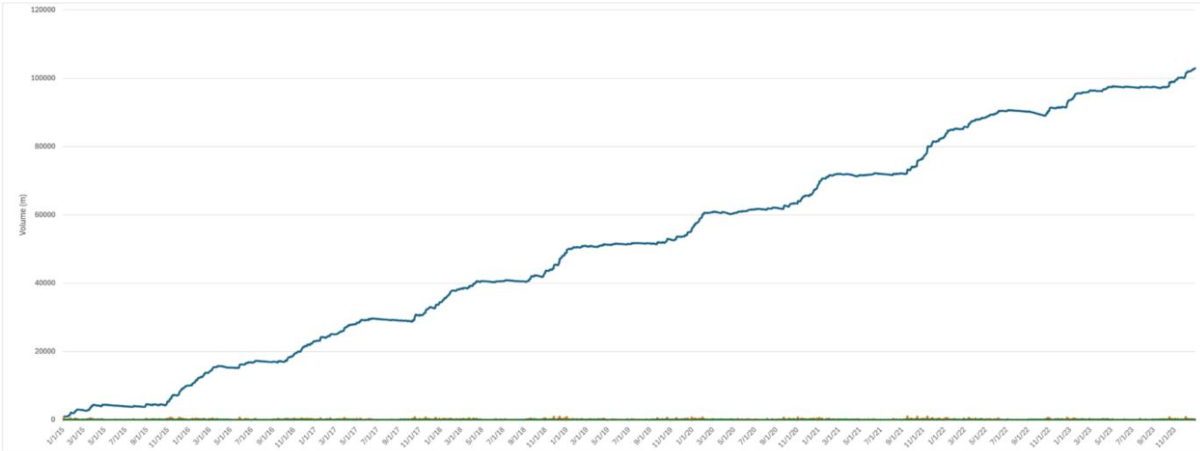

Figure 14: Water Balance Including All Three Building Catchments

10.2.2 Cistern Sizing

The initial water balance showed an annual precipitation excess, so a second calculation a second calculation was done limited to the IKB roof catchment alone (Figure 15). This analysis identified a seasonal water storage requirement of 3,000 cubic meters. Although the cistern sizing was based on the IKB catchment's specific usage needs, the biodetention pond retains its initial sizing for all three roofs, for future expansion capability.

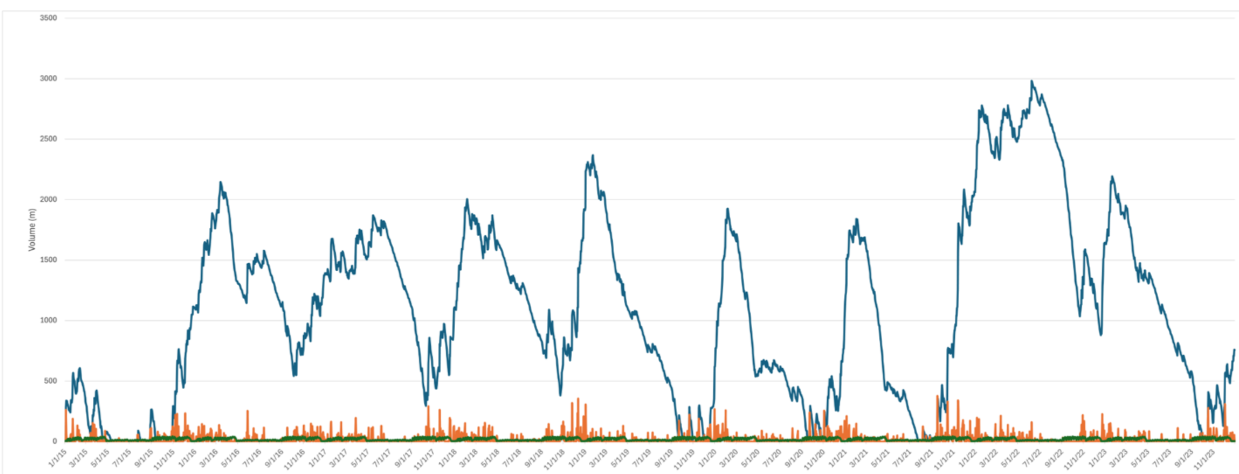

Figure 15: Water Balance with Only IKB Roof Catchment

10.3 Hydraulics Calculations

The following overview of hydraulics calculations applies to pressurized water pipes that connect:

1. The biodetention pond to the sand filters
2. The sand filters to the cisterns

3. The outlet of the cistern to the remaining treatment and reuse

This involved estimating head losses due to elevation changes, friction within the pipe, and minor losses from fittings. These calculations allowed for the determination of the total dynamic head, which was then used to estimate the pipe sizes needed to meet flow requirements. All supporting calculations, including parameters used, are documented in Appendix B.

The assumptions used in these calculations are:

- The dynamic viscosity is 10^{-4} Pas;
- The friction factor is 0.032;
- The minor losses are 1 for the exit, 0.5 for the entrance, and 0.2 for the gate valves.

For the pump sizing, the Grundfos quick pump sizing tool was used through inputting the head loss, and finding a pump that fits [13]. The pump curves that output from this are also included in Appendix A.

10.4 Treatment Calculations

Calculations were conducted in Microsoft Excel to appropriately size each component, determine required doses, and estimate target removal rates for the treatment system. Select values were also informed by literature reviews, industry best practices, and specifications from commercially available products. Calculations for treatment components are included in Appendix B.

10.4.1 Sand Filters

To determine the dimensions of the sand filters, two initial values were used. The first being the filtration rate of 6 m/hr (6000 L/m^2/hr), chosen due to the expected quality of rainwater with low TSS concentrations. This rate also aligns with typical rapid sand filtration units, which are commonly used in urban settings with loading rates ranging from 3000 to 6000 L/m^2/hr [14]. The second being the maximum expected discharge from the detention pond of 21.25 m^3/hr. This flow was halved to 10.63 m^3/hr by adding an additional sand filter column to operate in parallel to improve the overall H:D ratio, operational efficiency, and O&M friendliness. With the filtration rate and flow rate, each circular filtration column was determined to have a surface area of 1.77 m^2 and a diameter of 1.1 m, based off the following relationship shown in Equation 1.

Equation 1: Filtration Rate

$$Filtration\ Rate = \frac{Flowrate}{Surface\ Area}$$

To determine the height of each sand filter, two factors were taken into consideration: media depth and water depth above the media. The media, which consisted of a 0.6 m layer of fine quartz sand and 0.1 m a gravel base, would contribute a total of 0.7 m of required height [15].

On top of that, the recommended depth of water above the media for optimal filtration speed and performance is 1.5 m [16]. Therefore, the required height of each sand filter was determined to a total of 2.2 m tall, as illustrated in Figure 16.

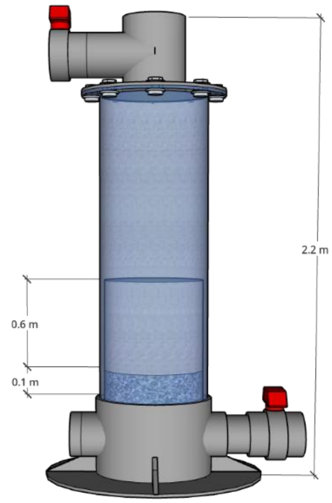

Figure 16: 3D Visual of a Sand Filter

With the dimensions of each sand filter determined, various other measures can be simply derived such as required sand volume, gravel volume, column volume, and empty bed contact time (EBCT), which is the time water spends in contact with the media using Equation 2.

Equation 2: EBCT

$$EBCT = \frac{Volume\ (media)}{Flowrate}$$

To determine the expected head loss through each sand filter, the modified Hazen-Williams Equation, specifically through granular media was used, along with the calculated values above. The head loss was calculated to be <1 m with conservative values, with literature studies stating head loss values ranging between 2 to 5 m [17]. Therefore, an assumption was made that it would be at the discretion of the operator to determine when backwashing was necessary based on BMPs. Backwashing frequency of the filters will typically range occur every 2 to 7 days.

A summary of the calculated results for the sand filters can be found in

Table 6 below. Additional details on the calculations can be found in Appendix B.

Table 6: Summary of Sand Filter Calculations

Height (m)	2.2
Diameter (m)	1.1
Flow Rate (m3/hr)	10.63
Filtration Rate (m/hr)	6
Sand Depth (m)	0.6
Sand Volume (m3)	1.06
Gravel Depth (m)	0.1
Gravel Volume (m3)	0.18
EBCT (min)	7
Head loss (m)	0.79

10.4.2 Bag Filters

The bag filters and bag filter housing units used for this system are Eaton's POLYLINE single bag filter housing units, with a bag size of #2 and dimensions of 1.27 m tall and 0.48 m wide [18]. Minimal calculations were required due to the component being commercially available in a pre-existing size and configuration. Head loss values were checked using a similar method as the sand filters but were determined to be negligible due to its minimal effects on flow. More details of the bag filters and bag filter housing units can be found in Appendix A and B, along with the product specification sheets and drawings.

10.4.3 UV Disinfection

The UV disinfection reactor used for the system will be a commercially available product, specifically the Viqua PRO24-100 [19]. This unit is originally designed for flowrates up to 5.45 m^3/hr (24 gpm) at a UV dose of 100 mJ/cm^2. Given the max flow of IKB's 2023 water usage data of 1.8 m^3/hr (8 gpm), as well as the inverse relationship between UV dose and flow rate, a UV dose of 300 mJ/cm^2 is achieved for the system [12]. This solidifies the inactivation of 4-log removal of microorganisms, including cryptosporidium, giardia lamblia, and viruses, as it exceeds the 186 mJ/cm^2 UV dose as seen in

Table 7 [20].

Table 7: UV Dose Requirements for Inactivation Credit

Log Credit	Cryptosporidium UV Dose (mJ/cm^2)	Giardia lamblia UV Dose (mJ/cm^2)	Virus UV Dose (mJ/cm^2)
0.5	1.6	1.5	39
1.0	2.5	2.1	58
1.5	3.9	3	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

The following equations were used to complete calculations for residence time and UV Dose:

Equation 3: Residence Time

$$Residence\ Time = \frac{Reactor\ Volume}{Volumetric\ Flowrate}$$

Equation 4: UV Dose

$$UV\ Dose = Residence\ Time * Intensity$$

The residence time within the reactor was determined to be 16.4 seconds. In terms of energy usage, given the reactor's energy demand of 230 watts, and an overestimation of assuming the reactor will operate year-round at 8760 hrs/yr, the total energy usage per year would equate to 2015 kWh. Additional details on the commercially available Viqua PRO24-100 UV disinfection system can be found in Appendix B along with the production specification sheet.

11 Hazard and Risk Assessment

The designed system has several connected components, and they each introduce hazard risks into the project. At the collection point, blockages on the rooftops could cause overflow on the roofs and prevent flow into the system. Water quality degradation in the detention pond due to algae growth and external contamination is also possible. Both the primary and secondary filters have a possibility of failure in the case of clogging or wear and tear. The water stored in the cisterns is relatively stagnant, so microbial growth is also possible although it would be treated further down the system. UV disinfection failure from power issues or wear and tear would result in poor water quality, posing a threat to human health. These hazards pose operational, environmental, as well as public health risks if they are not managed properly.

Among the listed components' hazards, the UV disinfection system is expected to have the highest risk. This node is the final treatment operation before the water is sent to its reuse application, so improper treatment will pose immediate health hazards at the reuse application point.

To assess this hazard, possible deviations and causes were identified as well as their associated consequences. The severity and likelihood of the consequences were also considered, and recommendations were made for each deviation case. A detailed preliminary hazard analysis was then conducted which can be found in Appendix D. Notably, significant deviations included no flow, low UV intensity, no UV output, high turbidity, and short exposure. Although each component of the design, the UV disinfection unit was chosen to be a critical node, as focus on the unit ensures the safety of human health.

12 Environmental Assessment

The Reviewable Projects Regulation in BC determines whether or not a project requires an environmental assessment [21]. This project falls under a “Water Management Project” which is a reviewable category and is therefore subject to an environmental assessment.

The environmental impacts through the development and implementation of this project are estimated to be a net positive. One of the main requirements for land use was that no trees would be removed to make room for the design. This requirement was met, and the footprint of the designed system is limited to the area that it takes on the ground. Unfortunately, it was not possible to completely eliminate emissions. During the construction of the cisterns and detention pond, heavy machinery will be required. As a result, CO_2, and particulate matter will be released into the surrounding environment, affecting air quality during construction [22]. Each m^3 of concrete production and construction releases approximately 410 kg of CO_2 [23]. With a total of approximately 1000 m3 of concrete used for the cisterns and biodetention pond, an estimated 410 metric tonnes of CO2 will be released into the atmosphere during construction [24]. However, after the project is complete, pollution will be affected by the energy source used in treatment, which is outside the scope of this project. A key component of the design is a detention pond, which provides an area for ecosystem growth for both plants and animals. Considering the system was designed with climate change in mind, it is resilient to harsher weather conditions and is expected to be functional for several decades. Possible risks include leaks from the cisterns and bio-detention pond, however the quality of the water at those stages is not harmful to the environment or humans.

13 Economic Assessment

13.1 Capital Costs

The total capital costs required for the project is projected to be $3.5 million CAD with the bulk of it being the two main components of the system: the detention pond and the cisterns. The total costs for both detention pond and cisterns are roughly $1.1 million. The remaining costs are all significantly minute compared to the two except contingency. Using 35% Class D estimates, $900,000 is calculated to be the cost needed for contingency. Instrumentation & Controls is 13% of purchased equipment costs and mobilization & demobilization is 5% of total costs. A simplified pie chart can be seen below in Figure 17 and more detail can be seen in Appendix C.

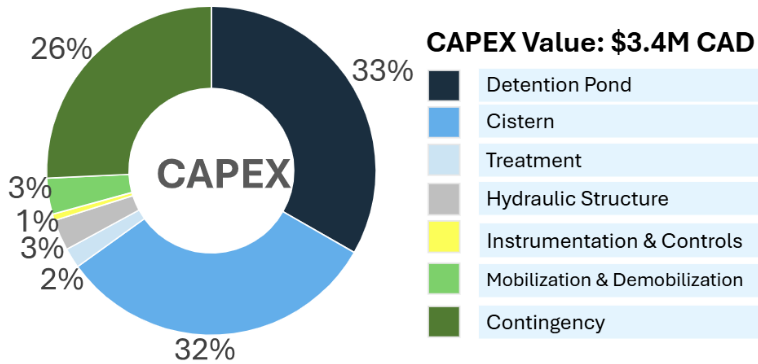

Figure 17: CAPEX

13.2 Operation & Maintenance Costs

The annual OPEX is projected to be $90,000 CAD. The majority of this is derived from operator salary. The system can operate relatively autonomous, but a trained professional must be present on-site daily to ensure proper functioning of the system, as well as periodically backwashing the sand filters. The remaining costs are mainly for maintenance of the various components of the system. These costs are minimal compared to operator salary with the highest being hydraulic structures at $13,050 annually. A simplified pie chart can be seen below in Figure 18 and more detail can be seen in Appendix C.

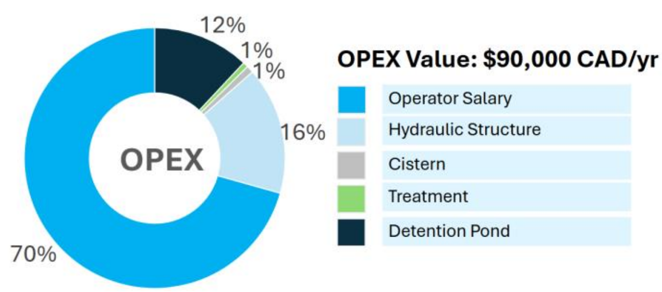

Figure 18: OPEX

13.3 Hydraulics Economic Assessment

The hydraulics are estimated to cost about $100,000 as CAPEX. About $60,000 of this is for the pumps, and the remaining $40,000 is the piping. Pumps are estimated to cost about $10,000, with most pumps available for this capacity on the market costing between $8,000 and $12,000 [13]. There are three pumps in the system, each needing a pump on standby. The pipes have their cost estimated per metre, with the unit costs changing for the different diameters of pipe [25] [26]. The gate valves are estimated to cost $2,500, with there being 6 gate valves in the system [27]. The construction costs are assumed to be included in this estimate.

The annual OPEX cost for the hydraulics is $13,000. This is made up of two costs: pump replacement costs, and electrical costs. The pumps need to be replaced every 10 years, so this is represented as 10% of the pump cost being included in the annual OPEX [13]. The electrical cost is assumed to be 12.5% of the pump costs, following the rule of thumb that the electrical costs 10-15% of the purchased equipment costs.

13.4 Bioretention Economic Assessment

The capital cost estimation for biodetention use methods from the Greenest City Scholars Program. Raingarden and bioswale costs, originally quoted at $20/sq ft and $50/sq ft respectively in 2016, were adjusted for inflation to 2025, resulting in updated estimates of $25/sq ft for raingardens and $63/sq ft for bioswales, inclusive of construction costs based on Vancouver projects [28].

The excavation required for the biodetention pond—estimated at $2,000 CAD per cubic meter—was added separately, as this cost was not inherently covered in the Greenest City Scholars' estimates due to variability in raingarden excavation requirements [29]. Including these excavation costs along with additional infrastructure such as benches and signage, the project's total estimated capital expenditure (CAPEX) stands at $1.7 million CAD. The OPEX was calculated to be $5,500 CAD which is mostly just replacing soils and plants, these calculations can be seen in Appendix C.

13.5 Cistern Economic Assessment

The costs for the cistern component are relatively straightforward. Due to the nature of the cistern being made of concrete, it is difficult to pre-assemble it and transport it on-site. It is much more feasible to construct the cistern on-site. In addition, due to its immense size, there are no pre-built cisterns on the market of this size. Thus, a novel design must be utilized. Approximately $750,000 is the cost required for concrete for the cisterns, $15,000 is needed for reinforced concrete base [30] [31]. Using the UBC Technical Guidelines, 45% of the purchased equipment (PE) cost will be the costs required for installation [7]. Therefore, about $341,000 is needed for installation. This all sums up to roughly $1,100,000 for the total CAPEX of the cistern component.

As for the operations and maintenance, the cisterns are relatively autonomous with daily checks by the operator and annual cleaning of the cisterns themselves. As the operator's salary is its own category, the actual costs for the cisterns are kept to a minimum at $600 annually.

13.6 Treatment Economic Assessment

The CAPEX of the treatment components will total to just over $66,000 CAD. This comprises of three sand filters, including the housing units and media, two bag filter units, including the housing units and bag filters, and two UV disinfection systems. The unit price for both sand and gravel from local retailers were $85/m^3 and the unit cost for a single bag filter $6.08. A detailed breakdown can be found in Table 8.

Table 8: CAPEX of Treatment Components

	CAPEX	Cost	References
3x Sand Filters	Clear Sand Filter Housing Unit	$24,000.00	[32]
	Sand Media	$270.94	[33]
	Gravel Media	$45.16	[34]
2x Bag Filters	Bag Filter Housing Unit	$7,643.15	[35]
	Bag Filter	$12.16	[36]
2x UV Reactors	UV Reactor Unit	$13,956.80	[37]
	Installation (45% of PE)	$20,519.98	[7]
	Total	**$66,448.18**	

As for OPEX, the annual cost for the treatment components will total to just over $800 CAD. This comprises of a normalized value for sand filter media replacement (occurs every 3 to 5 years), bag filters (replaced annually), UV lamps (replaced annually), and energy usage of the UV reactors. Table 9 summarizes the above findings.

Table 9: OPEX of Treatment Components

OPEX	Cost
Media Replacement (normalized)	$79.02
Bag Filter	$12.16
UV Lamps	$500.00
Energy Use [38]	$210.35
Total OPEX per year	**$801.52**

14 Commissioning and Startup Plan

To ensure the components and system function properly, a commissioning and startup plan will be followed. To start, the equipment specifications will be reviewed to make sure they follow any regulatory guidelines. A visual inspection of each apparatus will check for any obvious damage. Then, each component will be tested individually to confirm their operational readiness. The detention pond and cistern will be constructed and tested on site to check for any leaks. Once each individual component is verified to be functional, the system as a whole will be tested in a simulated environment. A manual inflow of water will commence, and the progression of water through the system will be observed. Retention times and flow rates will be monitored to ensure they match the expected specifications and requirements. At the end of the process, the water should meet the required quality standards. As such, the water will be tested to ensure the parameters are met. Finally, the rooftop collection points will be connected to the inlets, and gutters will be checked for blockages before handover. During the commissioning process, an operator will be trained to perform maintenance, troubleshooting, and other operational procedures.

If design issues arise during commissioning, temporary workarounds can be used depending on the severity of the problem. However, in the case that modifications are necessary, the design process would resume until an updated design is validated and finalized. At that point, the testing process would begin again, and handover would not occur until all checks are complete.

15 Conclusion and Recommendations

This project presents a rainwater capture and reuse system designed for UBC's North Campus to address flooding and offset potable water demand in summer drought. The final system includes five components: a biodetention pond, sand filtration, concrete cisterns, bag filters, and UV disinfection. Rainwater from the IKB, LIFE, and Rec North buildings is collected, filtered, and treated to meet BC 43210 drinking water quality standards before reuse in IKB. The system was sized for a 100-year storm under future climate conditions using IDF_CC 7.0 and PCSWMM to ensure long-term resilience.

The estimated capital cost is $3.4 million CAD, with $90,000 CAD in annual operating costs. While the system does not generate direct revenue, it reduces campus water demand and enhances sustainability. A commissioning and startup plan has been outlined to ensure performance and regulatory compliance.

Key recommendations include:

- Phasing the project and first implementing the biodetention pond to address current flooding.
- Collaborating with Musqueam representatives on plant selection in the bioretention area.
- Scaling the system to serve nearby buildings using the oversized detention pond.

From a policy perspective, more policy is recommended on reuse of rainwater and decentralized systems. Also, the use of future-climate IDF curves in this project highlights the importance of updating rainfall design standards to reflect climate change scenarios like SSP5-8.5.

The team learned that aligning treatment levels with end-use, applying climate modeling, and important to integrated rainwater reuse design. Balancing regulatory, environmental, and operational requirements under limited site conditions shows the importance of iterative design, and clear task division.

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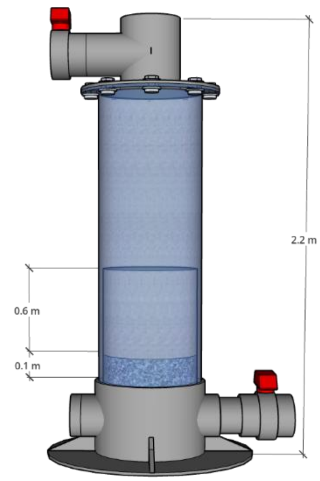
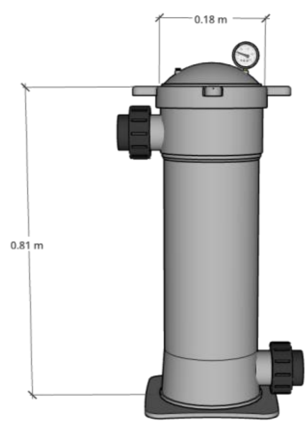
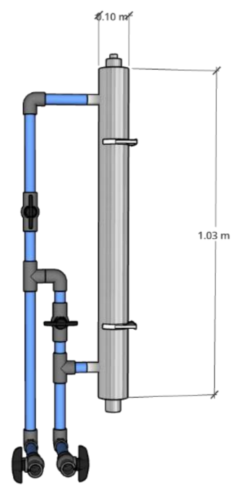
17 Appendix A: Drawings



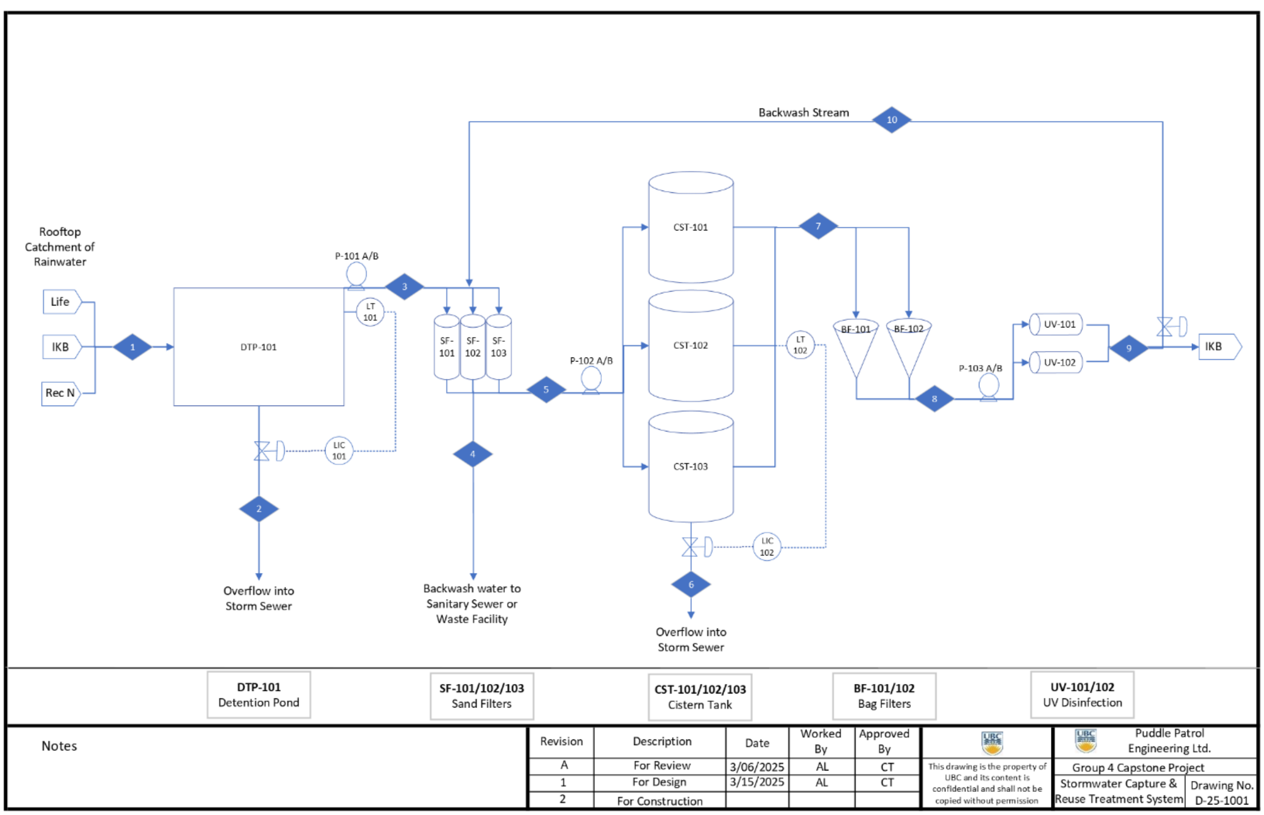
Appendix A 1: Sand Filter



Appendix A 2: Bag Filter



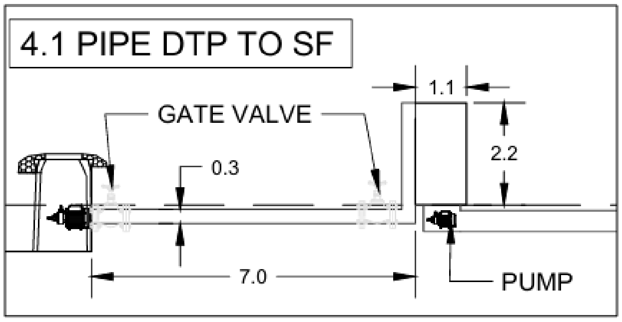
Appendix A 3: UV Disinfection Unit

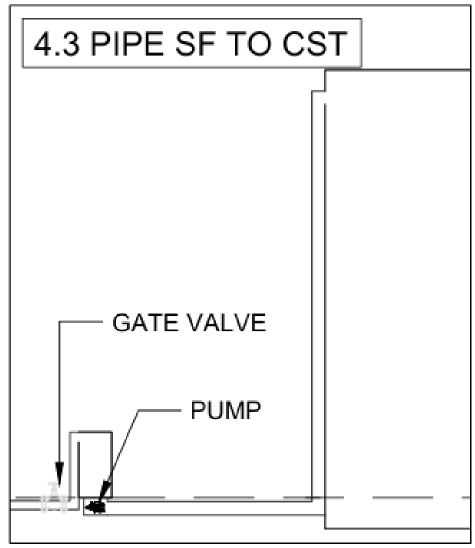


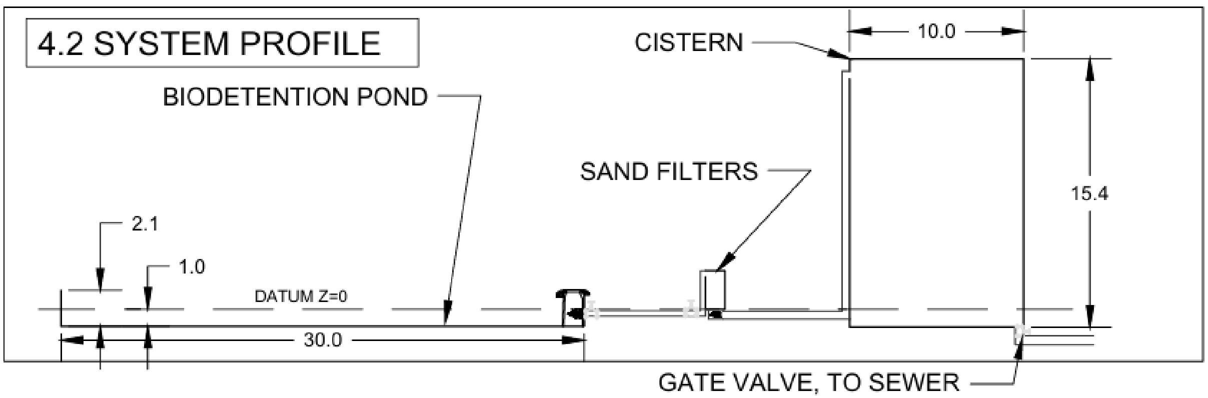
Appendix A 4: System Process Flow Diagram

Appendix A 5: System Layout

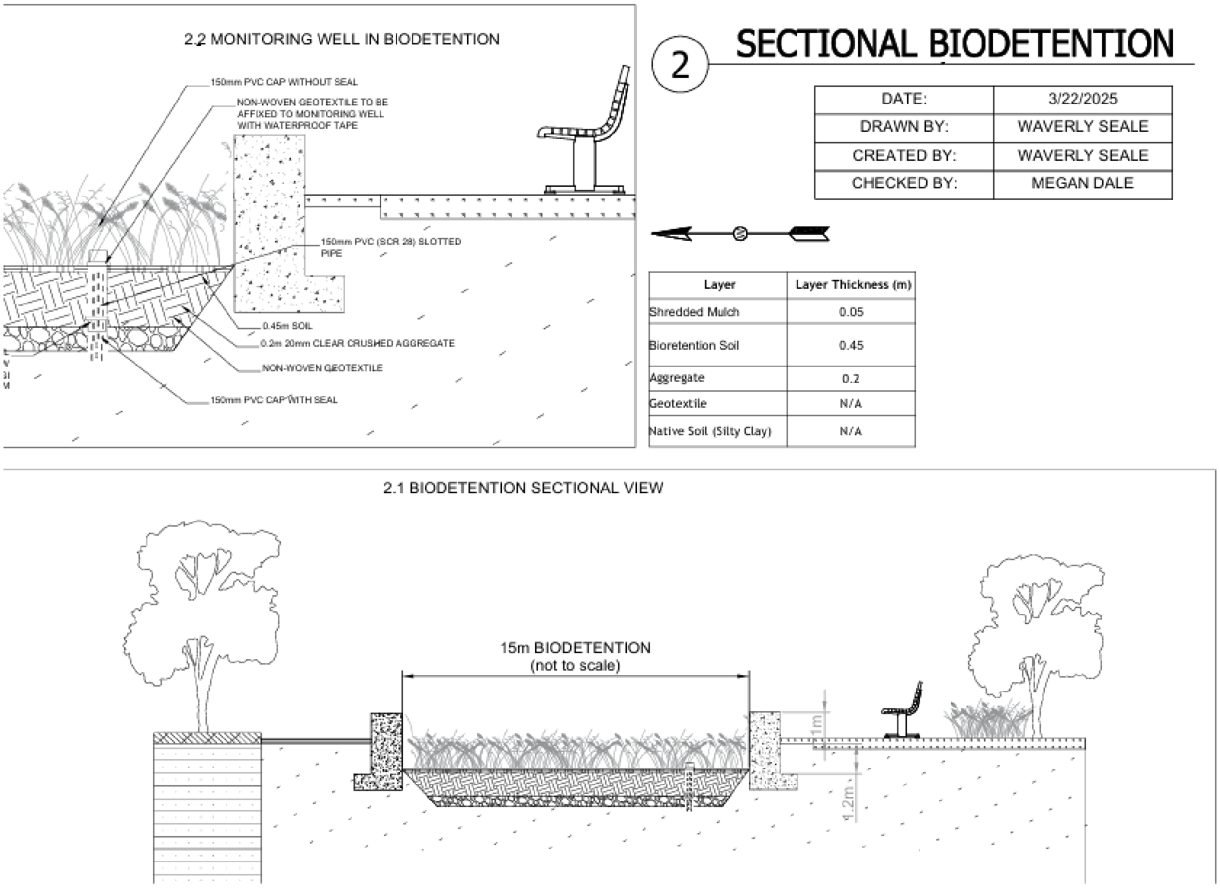
A	B
4.0 PROFILE DRAWING	
DATE	3/25/2025
DRAWN BY	MEGAN DALE
DESIGNED BY	MEGAN DALE
CHECKED BY	WAVERLY SEALE







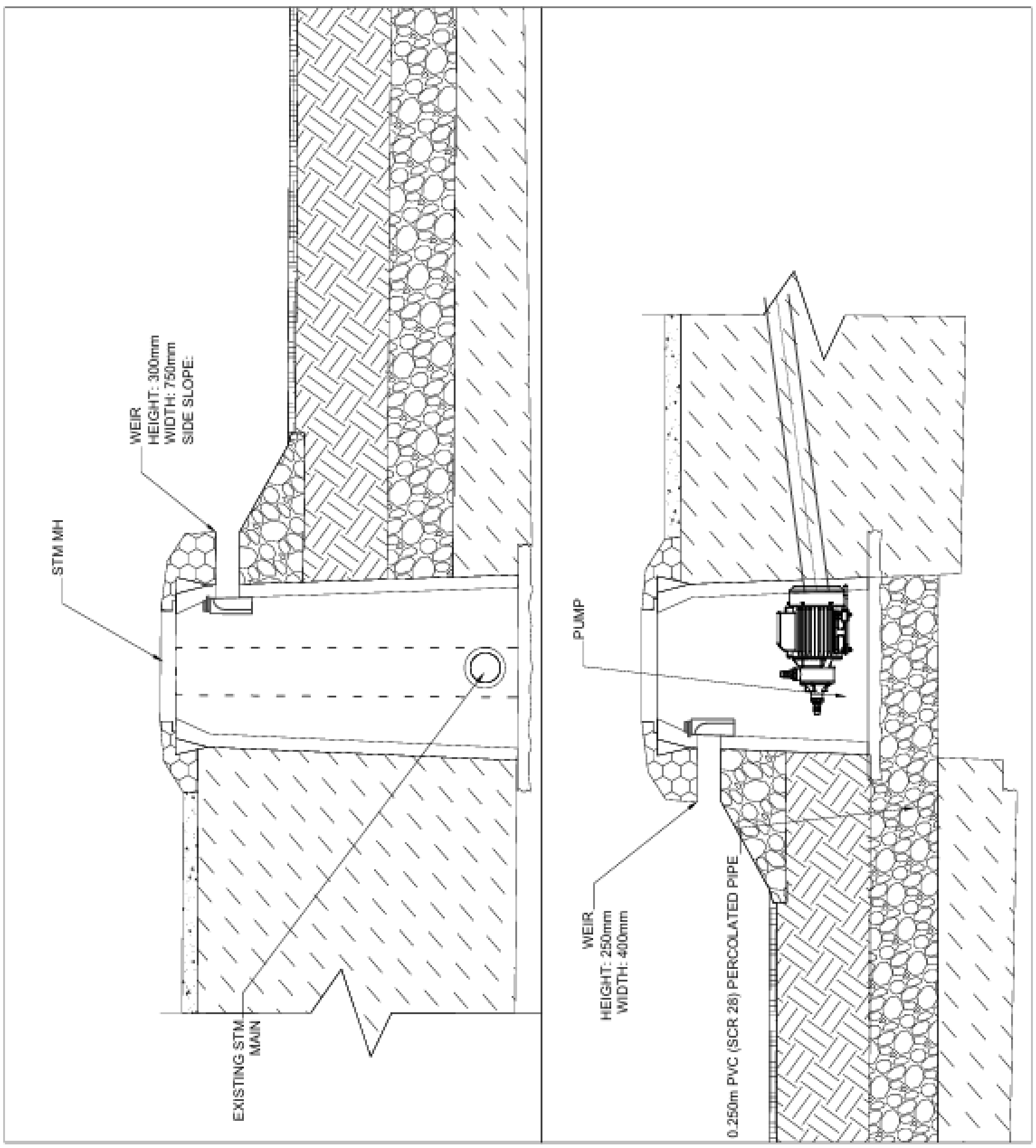
Appendix A 6: Profile Drawings



Appendix A 7: Biodetention Sections

3 BIODETENTION PROFILE CONNECTIONS

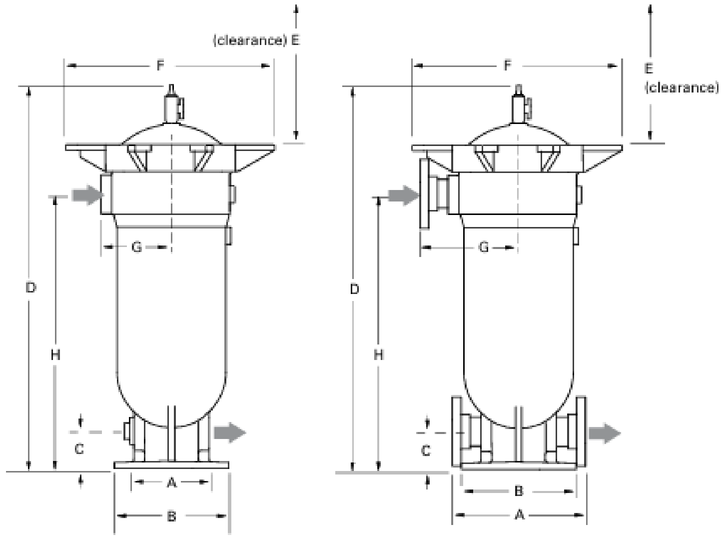
DATE:	2024-03-03
DRAWN BY:	WAVERLY SEALE
CREATED BY:	WAVERLY SEALE
CHECKED BY:	MEGAN DALE



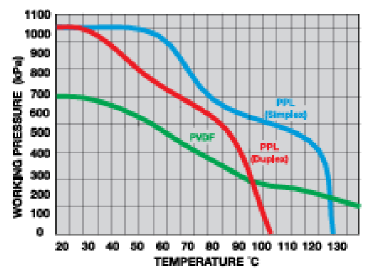
Appendix A 8: Biodetention Connections

Applications

Applications	
Coarse filtration > 500 µm	✓
Medium filtration > 10 µm	✓
Fine filtration < 10 µm	
Pre-filtration	✓
Safety filtration	
High volume	
Batch filtration	✓
Circuit filtration	✓
Continuous filtration	
Solvents, paints	
Fats and oils	
Catalyst, activated carbon	
Acids, bases	✓
Petrochemicals	
Water, waste water	✓
Chemical industry	✓
Pharmaceuticals	
Metal cleaning	
Automotive	
Electronics	✓
Food and beverage	
Paint and lacquer	
Water treatment	✓
Galvanic industry	✓



Operating temperature/ pressure for POLYLINE single bag filter housings



Dimensions - mm

Models	A	B	C	D	E	F	G	H
PBF-0101	165	254	83	867	510	467	156	610
PBF-0102	165	254	83	1273	920	467	156	1016
PBF-0101	290	254	83	867	510	467	219	610
PBF-0102	290	254	83	1273	920	467	219	1016

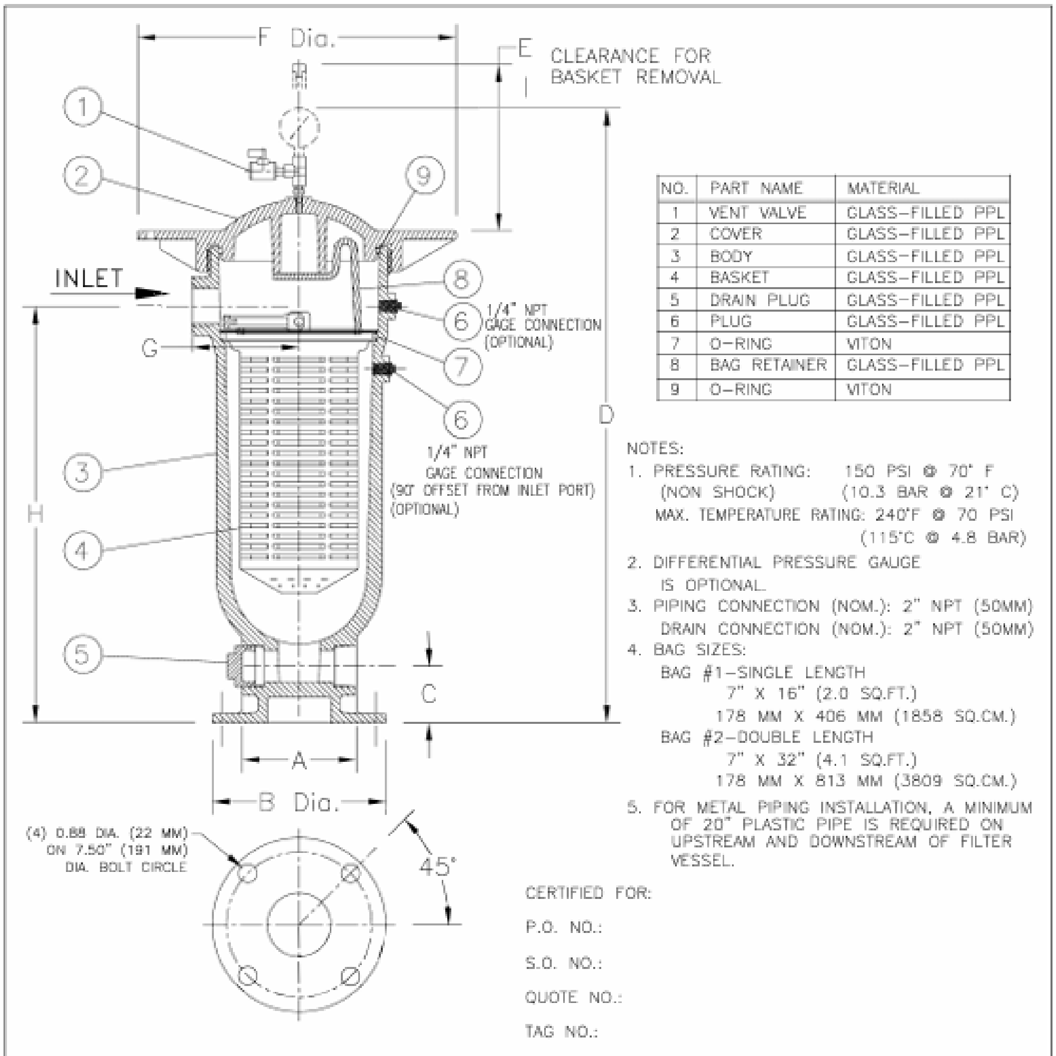
Dimensions for reference only and approximate. Exact dimensions for installation purposes available on request.

Technical data

Models	No. of filter bags	Size	Flow rate[1] m^3/h	Max. pressure bar	Max. temp. °C	Housing volume l	Housing weight kg	I/O connections
PBF-0101	1	1	12	10 @ 21 °C	115 @ 4.8 bar	25	23	2" BSP female thread
PBF-0102	1	2	24	10 @ 21 °C	115 @ 4.8 bar	36	29	2" BSP female thread
PBF-0101	1	1	12	10 @ 21 °C	115 @ 4.8 bar	25	25	DN 50 PN 16 (DIN flange)
PBF-0102	1	2	24	10 @ 21 °C	115 @ 4.8 bar	36	31	DN 50 PN 16 (DIN flange)

[1] Maximum theoretical flow based on water viscosity, filter bag specific.

Appendix A 9: POLYLINE Bag Filter Spec Sheet



PART NO.	A		B		C		D		E		F		G		H		WT. (DRY)	
	IN.	MM.	IN.	MM.	IN.	MM.	IN.	MM.	IN.	MM.	IN.	MM.	IN.	MM.	IN.	MM.	LBS.	KG.
FLT4201V	6.50	165	10	254	3.25	83	35.25	895	20	508	18.38	467	6.13	156	23.88	607	49	22.3
FLT4202V	6.50	165	10	254	3.25	83	51.25	1302	36	914	18.38	467	6.13	156	39.88	1013	63	28.6

EATON FILTRATION, LLC

NAME: POLYLINE BAG FILTER NPT THREADED CONNECTION SIZE 2" POLYPROPYLENE

DRAWN: FM | DATE: 10/24/19 | CERT. VAA | DATE: 10/24/19

SIZE: A | DWG NO: SD021000V | REV: A

ELECTRONIC FILE NAME: SD021000V

REF. ECR 0198289 | DATE 01/06/20

REV 8/00

Appendix A 10: POLYLINE Bag Filter Drawing

Photo is representative

Eaton FLT4202

Eaton POLYLINE Bag Filter Housing, PBF-0102-PO10-020N -NS-V-NNS, No. of Bags 1, Bag Size 02, Polypropylene, 10 Bar, NPT female thread 2"

General specifications	
PRODUCT NAME	Eaton POLYLINE Bag Filter Housing
CATALOG NUMBER	FLT4202
PRODUCT LENGTH/DEPTH	254 mm
PRODUCT HEIGHT	1273 mm
PRODUCT WIDTH	467 mm
PRODUCT WEIGHT	28.6 kg
CERTIFICATIONS	ISO 9001

Appendix A 11: POLYLINE Bag Filter Housing Spec Sheet

Specifications

	PRO24-100 (US EPA 2-log)
Part numbers	
North America (NEMA P-15)	660095-R (PRO24-100)
EU CEE (CEE 7-7)	660096-R
Flow rates	
UV dose	100 mJ/cm²
Validated flow	10, 15, 21, and 24 US gpm (UVT dependent)
Validated UVT*	75%, 85%, 90%, and 95%
Dimensions	
Chamber	41 in. x 4 in. (103 cm x 10 cm)
Inlet and outlet port size	1.25 in. MNPT x 1 in. FNPT combo
Shipping weight	31 lbs (14 kg)
Electrical	
Power consumption	230 W

* Refer to the Validation Chart for alternative UVT validated flow rates.

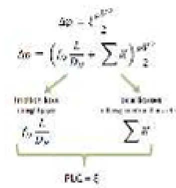
Appendix A 12: PRO24-100 UV Disinfection Spec Sheet

18 Appendix B: Calculations

Pressurized pipe from detention through to treatment, will pump water out of detention tank to sand filters

Parameter	Value	units
Q	6	L/s
Q (SI)	0.006	m3/s
L	7	m
z1	-0.4	m
z2	2.2	m
Deltaz	2.6	m
g	9.81	m2/s
density	1000	kg/m3
dynamic viscocity	1.00E-04	Pas
K_exit	1	-
K_entrance	0.5	-
K_valve	0.2	*if doing a gate valve
K_sum	1.7	-
f_assumed	0.032	-

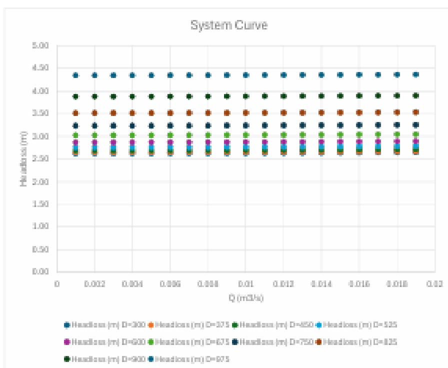
Fitting	Loss coefficient
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Short-radius elbow	0.9
Medium-radius elbow	0.8
Large-radius elbow	0.6
45 degree elbow	0.4
Closed return bend	2.2
Standard tee flow through run	0.6
Standard tee flow through branch	1.8
Square Entrance	0.5
Exit	1.0

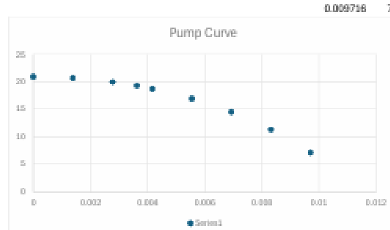


Diameters (mm)	Diameters (m)	Q (m3/s)	Headloss (m) D=300	D=375	D=450	D=525	D=600	D=675	D=750	D=825	D=900	D=975
300	0.3	0.001	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.51	3.88	4.34
375	0.375	0.002	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.51	3.88	4.34
450	0.45	0.003	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.51	3.88	4.34
525	0.525	0.004	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.51	3.88	4.34
600	0.6	0.005	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.51	3.88	4.35
675	0.675	0.006	2.62	2.65	2.69	2.76	2.87	3.02	3.23	3.52	3.88	4.35
750	0.75	0.007	2.62	2.65	2.69	2.76	2.87	3.02	3.24	3.52	3.88	4.35
825	0.825	0.008	2.62	2.65	2.69	2.77	2.87	3.03	3.24	3.52	3.88	4.35
900	0.9	0.009	2.63	2.65	2.70	2.77	2.87	3.03	3.24	3.52	3.88	4.35
975	0.975	0.01	2.63	2.65	2.70	2.77	2.88	3.03	3.24	3.52	3.88	4.35
		0.011	2.63	2.65	2.70	2.77	2.88	3.03	3.24	3.52	3.89	4.35
		0.012	2.63	2.66	2.70	2.77	2.88	3.03	3.24	3.52	3.89	4.35
		0.013	2.63	2.66	2.70	2.77	2.88	3.03	3.24	3.52	3.89	4.35
		0.014	2.64	2.66	2.70	2.77	2.88	3.03	3.24	3.53	3.89	4.36
		0.015	2.64	2.66	2.71	2.78	2.88	3.04	3.25	3.53	3.89	4.36
		0.016	2.64	2.66	2.71	2.78	2.89	3.04	3.25	3.53	3.89	4.36
		0.017	2.64	2.67	2.71	2.78	2.89	3.04	3.25	3.53	3.90	4.36
		0.018	2.65	2.67	2.71	2.78	2.89	3.04	3.25	3.53	3.90	4.36
		0.019	2.65	2.67	2.72	2.79	2.89	3.05	3.26	3.54	3.90	4.37

Qmin [US g	Qmax [US g	Q [US gpm	H [ft]	P2 [HP]	P1 [HP]	Eta2 [%]	Eta1 [%]	NPSH [ft]
57.5	154							
		0	68.51	0.827	0.973	0	0	5.094
		22	67.73	1.09	1.25	34.69249	30.18254	5.027
		44	65.39	1.37	1.56	52.884	46.66052	5.023
		57.5	63.13	1.55	1.74	59.24027	52.53169	5.019
		66.1	61.34	1.65	1.86	61.94289	55.05026	5.483
		88.1	55.44	1.9	2.13	64.89389	57.87105	7.665
		110	47.44	2.12	2.37	62.25555	55.59699	10.34
		132	36.93	2.31	2.58	53.36649	47.6745	14.87
		154	23.25	2.46	2.76	36.742	32.81591	25.43

Q (m3/s)	H (m)
0	20.88185
0.001388	20.6441
0.002776	19.93087
0.003628	19.24202
0.00417	18.69843
0.005558	16.89811
0.00694	14.45971
0.008328	11.25628
0.009716	7.0888



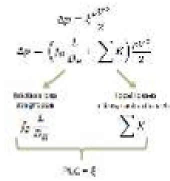


Appendix B 1: Detention to Treatment

Pressurized pipe from detention through to treatment, pump water from base of filters to cistern

Parameter	Value	units
Q	6	L/s
Q (SI)	0.006	m3/s
L	31	m
z1	-0.6	m
z2	14	m
Deltaz	14.6	m
g	9.81	m2/s
density	1000	kg/m3
dynamic viscocity	1.00E-04	Pas
K_exit	1	-
K_entrance	0.5	-
K_valve		*if doing a gate valve
K_sum	1.5	-
f_assumed	0.032	-
h_filters	5	m

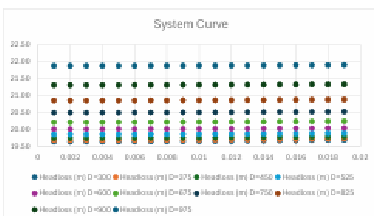
Fitting	Loss coefficient
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Short-radius elbow	0.9
Medium-radius elbow	0.8
Large-radius elbow	0.6
45-degree elbow	0.4
Closed return bend	2.2
Standard- tee flow through run	0.6
Standard- tee flow through branch	1.8
Square Entrance	0.5
Exit	1.0

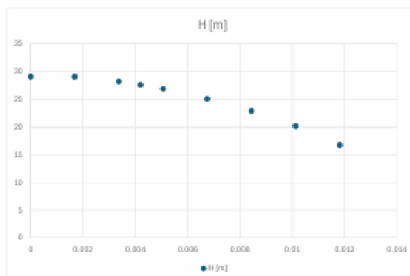


Diameters (mm)	Diameters (m)	Q (m3/s)	Headloss (m)									
			D=300	D=375	D=450	D=525	D=600	D=675	D=750	D=825	D=900	D=975
300	0.3	0.001	19.64	19.68	19.75	19.86	20.01	20.22	20.49	20.85	21.31	21.88
375	0.375	0.002	19.64	19.68	19.75	19.86	20.01	20.22	20.49	20.85	21.31	21.88
450	0.45	0.003	19.64	19.68	19.75	19.86	20.01	20.22	20.49	20.85	21.31	21.88
525	0.525	0.004	19.64	19.68	19.75	19.86	20.01	20.22	20.49	20.85	21.31	21.88
600	0.6	0.005	19.64	19.69	19.75	19.86	20.01	20.22	20.50	20.85	21.31	21.88
675	0.675	0.006	19.64	19.69	19.76	19.86	20.01	20.22	20.50	20.85	21.31	21.88
750	0.75	0.007	19.65	19.69	19.76	19.86	20.01	20.22	20.50	20.86	21.31	21.88
825	0.825	0.008	19.65	19.69	19.76	19.86	20.02	20.22	20.50	20.86	21.31	21.88
900	0.9	0.009	19.65	19.69	19.76	19.87	20.02	20.22	20.50	20.86	21.31	21.88
975	0.975	0.01	19.65	19.70	19.76	19.87	20.02	20.23	20.50	20.86	21.32	21.88
		0.011	19.66	19.70	19.77	19.87	20.02	20.23	20.50	20.86	21.32	21.88
		0.012	19.66	19.70	19.77	19.87	20.02	20.23	20.51	20.86	21.32	21.89
		0.013	19.66	19.70	19.77	19.88	20.03	20.23	20.51	20.87	21.32	21.89
		0.014	19.67	19.71	19.77	19.88	20.03	20.23	20.51	20.87	21.32	21.89
		0.015	19.67	19.71	19.78	19.88	20.03	20.24	20.51	20.87	21.33	21.89
		0.016	19.68	19.72	19.78	19.89	20.03	20.24	20.52	20.87	21.33	21.90
		0.017	19.68	19.72	19.79	19.89	20.04	20.24	20.52	20.88	21.33	21.90
		0.018	19.69	19.72	19.79	19.89	20.04	20.25	20.52	20.88	21.33	21.90
		0.019	19.69	19.73	19.79	19.90	20.04	20.25	20.53	20.88	21.34	21.90

1 pump

Qmin [l/s]	Qmax [l/s]	Q [l/s]	Q (m3/s)	H [m]	P2 [kW]	P1 [kW]	Eta2 [%]	Eta1 [%]	NPSH [m]
4.207	11.82	0	0	29.13	1.619	1.925	0	0	0.29
		1.688	0.001688	29.1	1.704	2.02	28.21285	23.80117	0.287
		3.376	0.003376	28.25	1.871	2.205	49.89344	42.34171	0.282
		4.207	0.004207	27.83	1.964	2.307	57.93914	49.33027	0.288
		5.065	0.005065	26.88	2.06	2.411	64.70572	55.27714	0.306
		6.753	0.006753	25.11	2.238	2.604	74.15305	63.74537	0.388
		8.441	0.008441	22.92	2.397	2.777	79.00775	68.21028	0.56
		10.13	0.01013	20.2	2.535	2.926	79.01515	68.46319	0.839
		11.82	0.01182	16.74	2.647	3.046	73.18129	63.59393	1.447





Appendix B 2: Detention to Treatment

			UV Reactor		
Total (m3/yr)		6917	Level of Treatment:	4 Log Removal	
	m3/day		m3/hr	gpm	
avg		18.9		0.8	3.5
max		42.50		1.8	7.8
			Q max demand of 8G)		8.0 gpm
	reactor volume / volumetric flow rate = res time		Residence Time		16.4 s
			Reactor Volume		8089.6 cm3
			Volumetric Flow Rate		491.9 cm3/s
	res time * intensity = UV dose --> log removal		UV Dose (for 2 log removal)		100 mJ/cm2

Product Specs	https://viqua.com/product/pro24-100/?replacement		
UV Dose		100	mJ/cm2
Flow		0.0015	m3/s
Power consumption		230	W
Length		103	cm
diameter		10	cm
area		78.53981634	cm2
volume		8089.601083	cm3

Proof that lower flowrate can achieve 4 log removal (viruses)		
design flow	24	gpm
design log removal	2	
system flow	8	gpm
Dose 24	100	mJ/cm2
Dose 8	300	mJ/cm2
4 log removal requirements for UV dose from the USEPA	186	mJ/cm2

$$\text{UV Dose} \propto \frac{1}{\text{Flow Rate}}$$

	https://www.eaton.com/ca/en-gb/catalog/filters-strainers/polyline.html#tab-3		
Bag Filters	https://www.filtersource.com/collections/bag-filter-housings/products/FLT4202V		
5 um	headloss considerations, very minimal		
Filter bag size	02 : Dia 7 x 32"L (180 x 810mm)		
diameter		0.18	m
height		0.81	m

	Sand Filter	Single Sand Filter	Two sand filter columns in parallel	Units
	Dimensions (H x D)			
	height	3.2	3.2	m
	diameter	2.12	1.1	m
max flowrate = volume of detention tank drained over 72 hrs	max flow rate from detention	21.25	10.625	m3/hr
	loading rate	6	6	m3/m2/hr
	Area	3.54	1.77	m2
	Diameter	2.12	1.50	m
convert loading rate to m/s (unit conversions)	Filter velocity	0.00167	0.00167	m/s
	Volume of column	7.79	3.90	m3
	Total media depth	0.7	0.7	m
	sand depth	0.6	0.6	m
	Volume of sand needed	2.13	1.06	m3
	gravel depth	0.1	0.1	m
	volume of gravel needed	0.35	0.18	m3
	min water above media	1.5	1.5	m
EBCT = bed volume / flowrate	EBCT	0.1167	0.1167	hr
	* time water spends in contact with treatment medium in the filter column	7	7	min

Headloss through sand filter (modified Hazen-Williams Eqn)		
C lower	150	
C upper	200	
velocity	0.00167	m/s
sand/media bed depth (slight over estimate)	0.7	m
d (effective grain size)	0.4	mm
hf lower	0.592	m
hf upper	0.789	m

$$h_f = \frac{C \cdot V \cdot L}{d^{1.33}}$$

Typical head loss is 2 to 5m

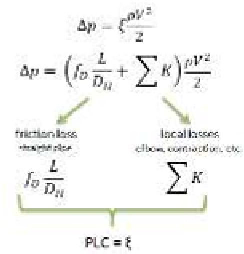
Sand Type	Grain Size (mm)	Typical CDC Value	Effect on Head Loss
Fine Sand	0.15 – 0.3	140 – 160	Higher Head Loss
Medium Sand	0.3 – 0.6	160 – 180	Moderate Head Loss
Coarse Sand	0.6 – 1.0	180 – 200	Lower Head Loss

Appendix B 3: Treatment

Pressurized pipe from detention through to treatment, will pump water out of cistern to reuse

Parameter	Value	units	
Q	6	L/s	
Q (SI)	0.006	m3/s	
L	31	m	
z1	-0.5	m	
z2	14	m	this is different - depends on reuse
Deltaz	14.5	m	
g	9.81	m2/s	
density	1000	kg/m3	
dynamic viscocity	1.00E-04	Pas	
K_exit	1	-	
K_entrance	0.5	-	
K_valve	0.2	*if doing a gate valve	
K_sum	1.7	-	
f_assumed	0.032	-	

Fitting	Loss coefficient
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Short-radius elbow	0.9
Medium-radius elbow	0.8
Large-radius elbow	0.6
45 degree elbow	0.4
Closed return bend	2.2
Standard- tee flow through run	0.6
Standard- tee flow through branch	1.8
Square Entrance	0.5
Exit	1.0



Diameters (mm)	Diameters (m)	Q (m3/s)	Headloss (m)									
			D=300	D=375	D=450	D=525	D=600	D=675	D=750	D=825	D=900	D=975
300	0.3	0.001	14.54	14.59	14.66	14.77	14.93	15.16	15.46	15.84	16.34	16.96
375	0.375	0.002	14.54	14.59	14.66	14.77	14.94	15.16	15.46	15.84	16.34	16.96
450	0.45	0.003	14.54	14.59	14.66	14.77	14.94	15.16	15.46	15.85	16.34	16.96
525	0.525	0.004	14.54	14.59	14.66	14.77	14.94	15.16	15.46	15.85	16.34	16.96
600	0.6	0.005	14.54	14.59	14.66	14.78	14.94	15.16	15.46	15.85	16.34	16.96
675	0.675	0.006	14.55	14.59	14.66	14.78	14.94	15.16	15.46	15.85	16.34	16.96
750	0.75	0.007	14.55	14.59	14.67	14.78	14.94	15.16	15.46	15.85	16.34	16.96
825	0.825	0.008	14.55	14.59	14.67	14.78	14.94	15.16	15.46	15.85	16.34	16.96
900	0.9	0.009	14.55	14.60	14.67	14.78	14.94	15.17	15.46	15.85	16.35	16.96
975	0.975	0.01	14.56	14.60	14.67	14.78	14.95	15.17	15.47	15.85	16.35	16.96
		0.011	14.56	14.60	14.68	14.79	14.95	15.17	15.47	15.86	16.35	16.97
		0.012	14.56	14.61	14.68	14.79	14.95	15.17	15.47	15.86	16.35	16.97
		0.013	14.57	14.61	14.68	14.79	14.95	15.18	15.47	15.86	16.35	16.97
		0.014	14.57	14.61	14.68	14.80	14.96	15.18	15.48	15.86	16.36	16.97
		0.015	14.58	14.62	14.69	14.80	14.96	15.18	15.48	15.87	16.36	16.98
		0.016	14.58	14.62	14.69	14.80	14.96	15.18	15.48	15.87	16.36	16.98
		0.017	14.59	14.63	14.70	14.81	14.97	15.19	15.48	15.87	16.36	16.98
		0.018	14.59	14.63	14.70	14.81	14.97	15.19	15.49	15.87	16.37	16.98
		0.019	14.60	14.64	14.70	14.81	14.97	15.19	15.49	15.88	16.37	16.99

Appendix B 4: Detention to Treatment

19 Appendix C: Economic Assessment

CAPEX	Costs		%	Notes
Detention Pond	$	1,151,600.39	33.55%	
Cistern	$	1,100,172.00	32.05%	
Treatment	$	45,928.20	1.34%	
Hydraulic Structures	$	104,363.63	3.04%	
Instrumentation & Controls	$	19,537.94	0.57%	13% of Purchased Equipment (treatment & hydraulic structures) from ENVE 401 CAPEX slide
Mobilization & Demobilization	$	121,080.11	3.53%	5% of total cost (civl 409 lecture)
Contingency	$	889,938.80	25.93%	35% CLass D Estimate
Total	$	3,432,621.07	100%	

Appendix C 1: Capital Costs

OPEX	Cost	%	Notes
Detention Pond	8173.848	9%	
Cistern	600	1%	
Treatment	801.525	1%	
Hydraulic Structures	13050	15%	
Operator Cost	64364	74%	
Total	**86989.37**	100%	

Savings per year assuming $2/m3 of water

13833.6

Appendix C 2: Operation & Maintenance Costs

Description	Unit	Quantity	Unit Price	Item Cost
GI Biodetention	**cu. m**	**450**	**$403.65**	**$181,641.07**
Benches	ea.	5	$525.00	$2,625.00
Signs	ea.	3	$2,000.00	$6,000.00
Excavation	cu. m	**450**	$2,064.30	$928,934.33
Total				$1,119,200.39
Contingency				50%
Class D Estimate				$1,678,800.59

Maintenance	Annual Fequency	Cost ($/m2)
Inspection and Monitoring	2	N/A
Vegetation Maintenance	1	N/A
Sediment Removal	0.2	$5,449.23
Inlet/Outlet Structure Cleaning	1	N/A
Cost Per Year		$5,449.23

Constants:		
Rain Garden Cost (2016)	20	$/sq ft
Rain Garden Cost (2025)	25	$/sq ft
Bioswale (2016)	50	$/sq ft
Bioswale (2025)	62.5	$/sq ft
Inflation Rate Since 2016	1.25	
Rain Garden Cost (2025)	269.0978763	$/m2
Bioswale (2025)	538.1957526	$/m2
Labour Cost ($/FTE)	$100,000	

	price	unit	source
Excavation:	2700	cy	https://www.autodesk.com/blogs/construction/a-guide-to-excavation-costs/#:~:text=To%20calculate%20excavation%20costs%2C%20multiply,of%20

Appendix C 3: Biodetention Costs

			UV Reactor		
Total (m3/yr)		6917	Level of Treatment:	4 Log Removal	
	m3/day		m3/hr	gpm	
avg		18.9	0.8	3.5	
max		42.50	1.8	7.8	
			Q max demand of IKB	8.0	gpm
	reactor volume / volumetric flow rate = res time		Residence Time	16.4	s
			Reactor Volume	8089.6	cm3
			Volumetric Flow Rate	491.9	cm3/s
	res time * intensity = UV dose --> log removal		UV Dose (for 2 log removal)	100	mJ/cm2

Product Specs	https://viqua.com/product/pro24-100/?replacement		
UV Dose		100	mJ/cm2
Flow		0.0015	m3/s
Power consumption		230	W
Length		103	cm
diameter		10	cm
area		78.53981634	cm2
volume		8089.601083	cm3

Proof that lower flowrate can achieve 4 log removal (viruses)		
design flow	24	gpm
design log removal	2	
system flow	8	gpm
Dose 24	100	mJ/cm2
Dose 8	300	mJ/cm2
4 log removal requirements for UV dose from the USEPA	186	mJ/cm2

$$\text{UV Dose} \propto \frac{1}{\text{Flow Rate}}$$

	https://www.eaton.com/ca/en-gb/catalog/filters-strainers/polyline.html#tab-3		
	https://www.filtersource.com/collections/bag-filter-housings/products/FLT4202V		
Bag Filters			
5 um	headless considerations, very minimal		
Filter bag size	02: Dia 7 x 32"L (180 x 810mm)		
diameter		0.18	m
height		0.81	m

	Sand Filter	Single Sand Filter	Two sand filter columns in parallel	Units
	Dimensions (H x D)			
	height	2.2	2.2	m
	diameter	2.12	1.1	m
max flowrate = volume of detention tank drained over 72 hrs	max flow rate from detention	21.25	10.625	m3/hr
	loading rate	6	6	m3/m2/hr
	Area	3.54	1.77	m2
	Diameter	2.12	1.50	m
convert loading rate to m/s (unit conversions)	Filter velocity	0.00167	0.00167	m/s
	Volume of column	7.79	3.90	m3
	Total media depth	0.7	0.7	m
	sand depth	0.6	0.6	m
	Volume of sand needed	2.13	1.06	m3
	gravel depth	0.1	0.1	m
	volume of gravel needed	0.35	0.18	m3
	min water above media	1.5	1.5	m
EBCT = bed volume / flowrate	EBCT	0.1167	0.1167	hr
	* time water spends in contact with treatment medium in the filter column	7	7	min

Headloss through sand filter (modified Hazen-Williams Eqn)		
C lower	150	
C upper	200	
velocity	0.00167	m/s
sand/media bed depth (slight over estimate)	0.7	m
d (effective grain size)	0.4	mm
hf lower	0.592	m
hf upper	0.789	m

$$h_f = \frac{C \cdot V \cdot L}{d^{1.33}}$$

Typical head loss is 2 to 5m

Sand Type	Grain Size (mm)	Typical CCC Value	Effect on Head Loss
Fine Sand	0.15 – 0.3	140 – 160	Higher Head Loss
Medium Sand	0.3 – 0.6	160 – 180	Moderate Head Loss
Coarse Sand	0.6 – 1.0	180 – 200	Lower Head Loss

Appendix C 4: Treatment Components Costs

Item	Cost per unit	Unit	Total	S
Pump 2	$ 9,000.00	2	$ 18,000.00	h
10" ductile iron pipe 350/50	$ 63.12	22.96588	$ 1,449.61	h
18" ductile iron pipe 6 m length	$ 3,750.00	5.166667	$ 19,375.00	h
10" ductile iron gate valve	$ 2,694.71	6	$ 16,168.26	h
Pump 1	$ 10,000.00	2	$ 20,000.00	h
Pump 3	$ 10,000.00	2	$ 20,000.00	
Backwash pipe	$ 68.01	137.7953	$ 9,370.77	U
			$ -	
			$ -	
Total			$ 104,363.63	
Contingency		50%	$ 52,181.82	
Grand total			**$ 156,545.45**	

42m

Extra sources:

24" ductile iron pipe	105.26	$/ft	h
			h
6" ductile iton pipe 350/50	30.75	$/ft	h
24" ductile iron pipe	105.26 $/ft		h

OPEX		$/year	
Pump replacement every 10 years	$ 58,000.00	$ 5,800.00	
Electrical	12.50%	$ 7,250.00	(
Total		$ 13,050.00	

Appendix C 5: Hydraulic Structures Costs

20 Appendix D: HAZOP PHA

PHA Worksheet

Node	UV-101/102: UV Disinfection Unit
Reference Documents	PDF - Process Controls Diagram
Design IntentConditions / Pa	DESIGN INTENT: The UV Disinfection unit (UV-101/102) is designed to kill and inactivate pathogens like viruses, bacteria, and protozoa in water. OPERATING CONDITIONS: The UV disinfection lamps (UV-101/102) operate at an average of approximately 40 C. PROCESS CONTROL: Feed to the UV disinfection lamps (UV-101/102) is sent through a pump from the bag filters (BF-101/102). HUMAN INTERACTION: There is no preventative maintenance required, nor sampling requirements. The column is inpsected through the regular annual plant maintenance shutdowns. SAFE LIMITS: The UV disinfection lamps can operate regularly in a range from 35 C and 50 C without process upsets. SAFETY DEVICES: Emergency shutoff switch

Deviation	Cause (Errors, Failures)	Consequence (without safeguards or operators)	Before Safeguards		Planned Safeguards	After Safeguards			mmendations / Comn	Responsibility
			Category	Severity		Category	Freq.	Risk Rank		
No/Less	Pump failure or closed valve	System failure and backup.	H&S			H&S		Low	Install flow sensors and allow for manual pump operation	Maintenance/Controls
			FIN	2	Flow sensors and manual	FIN	2			
			REP			REP				
			ENV			ENV				
Low UV Intensity	Bulb wear and tear or power drop	Incomplete Disinfection	H&S	4	UV Intensity monitors,	H&S	2	Medium	Log UV readings and inspect bulbs regularly	Operator
			FIN			FIN				
			REP	2		REP				
			ENV			ENV				
No UV Output	Power outage or system malfunction	Pathogens are not inactivated at all	H&S	5	Backup power, redundancy	H&S	2	High	Install backup power sources and implement a redundancy unit	Operator
			FIN			FIN				
			REP			REP				
			ENV			ENV				
High Turbitiy in Water	Poor filtration from bag filter	Lower UV effectiveness, resulting in incomplete disinfection	H&S	4	Filtration monitors	H&S	2	Medium	Install filtration monitors to measure performance	Operator
			FIN			FIN				
			REP			REP				
			ENV			ENV				
Underexposure	High flow rate or sensor failure	Incomplete Disinfection	H&S	4	UV Intensity monitors,	H&S	2	Medium	Install UV intensity monitors to ensure adequate exposure.	Operator
			FIN			FIN				
			REP			REP				
			ENV			ENV				
Overexposure	Low flow rate or pump failure	Wasted energy, UV bulb wear, inefficiency	H&S			H&S		Low	Monitor flow rate and consider redundancy for bulbs	Operator
			FIN	2	Redundant bulbs and	FIN	1			
			REP			REP				
			ENV			ENV				
Air bubbles in flow	Trapped air, or loose pipes	UV Scattered, incomplete disinfection	H&S	3	Flow sensors and manual	H&S	1	Low	Flow sensors and manual pump operation in case of emergency stop	Operator
			FIN			FIN				
			REP			REP				
			ENV			ENV				
Extreme Temperatures	Overheating	System damage and shutdown	H&S			H&S		Low	Monitor temperature to ensure proper system function	Operator
			FIN	3	Temperature monitors and	FIN	1			
			REP	2		REP	1			
			ENV			ENV				
Sensor Failure	Faulty flow sensor	Undetected incomplete disinfection	H&S	4	Redundancy and regular	H&S	1	Medium	Regular inspection to ensure sensors are functioning as designed	Operator
			FIN			FIN				
			REP			REP				
			ENV			ENV				

Appendix D 1: HAZOP PHA Worksheet

21 Appendix E: Equipment List

	EQUIPMENT LIST - STANDARD CAPSTONE FORM					Revision: 0 Date: April 2025	Puddle Patrol Engineering (Capstone Group 4)		
Equipment No.	**Equipment Name**	**Equipment Type**	**Material of Construction**	**Overall Dimensions**	**Volume**	**Service Fluid**	**Motor Size**	**Design Pressure**	**Design Temperature**
DTP-101	Detention Pond	Pond	Concrete	15 m x 30 m x 2 m	900 m^3	Rainwater	N/A	Atmospheric	N/A
SF-101	Sand Filter	Filter	Stainless Steel	2.2 m x 1.1 m	N/A	Rainwater	N/A	N/A	40 C
SF-102	Sand Filter	Filter	Stainless Steel	2.2 m x 1.1 m	N/A	Rainwater	N/A	N/A	40 C
SF-103	Sand Filter	Filter	Stainless Steel	2.2 m x 1.1 m	N/A	Rainwater	N/A	N/A	40 C
CST-101	Cistern	Cistern	Concrete	10m Diameter, 15m Height	1178 m^3	Partially Treated Water	N/A	Atmospheric	N/A
CST-102	Cistern	Cistern	Concrete	10m Diameter, 15m Height	1178 m^3	Partially Treated Water	N/A	Atmospheric	N/A
CST-103	Cistern	Cistern	Concrete	10m Diameter, 15m Height	1178 m^3	Partially Treated Water	N/A	Atmospheric	N/A
BF-101	Bag Filter	Filter	SS304	1.27 m x 0.40 m x 0.40 m	0.20 m^3	Partially Treated Water	N/A	N/A	40 C
BF-102	Bag Filter	Filter	SS304	1.27 m x 0.40 m x 0.40 m	0.20 m^3	Partially Treated Water	N/A	N/A	40 C
UV-101	UV Disinfection Unit	Disinfection	Stainless Steel	1.03 m x 0.10 m	N/A	Treated Water	N/A	N/A	50 C
UV-102	UV Disinfection Unit	Disinfection	Stainless Steel	1.03 m x 0.10 m	N/A	Treated Water	N/A	N/A	50 C
P-101 A/B	Pump	Pump	SS Impeller	N/A	N/A	Rainwater	N/A	N/A	N/A
P-102 A/B	Pump	Pump	SS Impeller	N/A	N/A	Partially Treated Water	N/A	N/A	N/A
P-103 A/B	Pump	Pump	SS Impeller	N/A	N/A	Treated Water	N/A	N/A	N/A

Appendix E 1: Equipment List