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An Integrated Software and Hardware Architecture for Gravity-driven and Remotely-operated Water Release

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

AN INTEGRATED SOFTWARE AND HARDWARE ARCHITECTURE FOR GRAVITY-DRIVEN AND REMOTELY-OPERATED WATER RELEASE

A thesis submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE

in

CIVIL ENGINEERING

by

Dogukan Ozecik

2021

To: Dean John L. Volakis
College of Engineering and Computing

This thesis, written by Dogukan Ozecik, and entitled An Integrated Software and Hardware Architecture for Gravity-driven and Remotely-operated Water Release, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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and Dean of the University Graduate School

Florida International University, 2021

DEDICATION

To my parents, Akif Ozecik and Hatice Ozecik, my sister, Kubra Ozecik, my uncle, Serhat Ozecik, and my relative, Mustafa Ozyuksel.

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ABSTRACT OF THE THESIS

AN INTEGRATED SOFTWARE AND HARDWARE ARCHITECTURE FOR GRAVITY-DRIVEN AND REMOTELY-OPERATED WATER RELEASE

by

Dogukan Ozecik

Florida International University, 2021

Miami, Florida

Professor Arturo S. Leon, Major Professor

The present study proposes an integrated real-time hardware and software architecture for gravity-driven and remotely-operated water release from storage units such as detention ponds, reservoirs, and wetlands using a siphon and conventional drainage pipe system. The hardware involves a communication component, a control function component, and a hydraulics component. The communication component consists of a Virtual Private Network (VPN) router that collects the Programmable Logic Controller (PLC) data and sends it to the remote center. The hydraulics hardware consists of an actuated butterfly valve, water level sensor, bilge pump, and air vent. Multiple flow release tests were carried out at the FIU Engineering Center to test the functionality and operational capability of the proposed system. The cost analysis for a 6" diameter siphon and conventional drainage pipe showed that they both are significantly less expensive than the widely used Supervisory Control and Data Acquisition (SCADA) system. The proposed low-cost systems can open new avenues for water management. Another proposition of this study is a derivation of an analytical equation for calculating the time-varying flow releases for both types of drainage. The validity of these equations was confirmed using the experimental flow release tests.

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CHAPTER 1: INTRODUCTION

1.1 Background and Motivation

Water is collected, stored, and released in storage systems such as reservoirs, natural/artificial lakes, and ponds for multi-purpose operations such as flood control, providing water supply, and generating hydropower, along with other environmental purposes (Rojali et al. 2020). Furthermore, it is also used for agricultural and recreational processes. Therefore, the common utilization of water also creates certain problems such as water management which an efficient water release system construction can do. Unnecessary release of water can be caused by a variety of events such as flooding, farm irrigation issues, poor water management along with other environmental and sanitation-related issues (Votruba and Broža 1989). Clearly, there are many factors that are impactful on water management.

To begin with, flooding is one of the most devastating natural disasters on the planet, possibly resulting in numerous human casualties as well as major economic, social, and infrastructural damages. Moreover, floodplains, which can be defined as lands that are near water sources that have the danger of flooding, are home to more than one billion people worldwide (Kang et al. 2019). Thus, it is evident that any possible disaster has the possibility of creating drastic damage to the communities. For instance, floods created negative effects on more than two billion people in the world in addition to the flood-related drought's leaving a dramatic impact on 1.5 billion people between 1998 and 2017 (Alberico et al. 2020). Furthermore, between 1996 and 2015, there were 107,743 documented floods in the United States, resulting in 1,563 direct deaths and over $167 billion in financial losses (Wallemacq 2018). From the examples given above, it can be claimed that floods can negatively impact the economy as much as human lives.

Apart from the floods, agriculture carries significant importance in the water management process. Poor or unplanned water management is a common problem for agriculture which is heavily relied on efficient productivity. Since the productivity is affected by all the changes that are associated with increased population, enhanced utilization of freshwater resources, pesticides and insecticides usage, reinforced regulatory demands on ecological protection bills, and a rise in the numbers of devastating natural disasters such as droughts, managing all of these factors require major attention to details during agricultural processes. However, the most essential factor is water which can create devastating outcomes in poor management or lack of resources, such as a possible case of drought. Not being able to provide the proper amount of water is a major threat for the countries that are heavily dependent on agriculture, such as the Caribbean that suffered from drought-related substantial loss of farm products along with its projected financial gain. Droughts’ impact on agriculture has turned into abiotic stress in mild and moist climate environments (Rey et al. 2017). The threat of drought is also impactful on developed countries. To illustrate, drought struck the southern United States between 1980 and 1981, causing crops in eastern Arkansas that were not irrigated previously like soybeans to become rapidly irrigated (Yaeger et al. 2018). Irrigation was stopped on over 470,000 acres of agriculture in the United States between 2008 and 2013 on account of surface and groundwater shortages. Due to the water demand for other consumers and their applications, pressure is being exerted on the agriculture industry to reduce its water footprint. This especially affects the urbanized cultures of the West (Stubbs 2016). Considering all these facts, it can be argued that creating an efficient water management process is the most vital part of the agricultural process due to its irreplaceable and valuable nature.

Finally, combined effects such as infrastructure constraints, accessible water, and the demand for it along with financial concerns, can be counted as the factors that influence reservoir releases. These releases can create major harm to the water habitats, which can be prevented by following certain criteria. Separate release targets for environmental necessities at the downstream level are usually based on the following criteria: (a) habitat extent and appropriateness, (b) modeled fish population at the downstream level and/or (c) ecological targets that are designated according to hydraulic, hydrologic, or regulatory standards. Therefore, the resulting flow regime can then help approximate the natural flow regime or take a more biophysical-social-hydrologic approach. Habitat and population modeling aim to optimize water release schedules to improve habitat capability, spawning, and ideally, the survival of a species at any of its life-history stages, such as fish. A traditional reservoir management technique for meeting environmental targets is to release any readily available water (Adams et al. 2017). Thus, it is obvious that external threats to the quality of available water for both living things and lands can be really devastating which indicates the necessity for improved and efficient methods.

All in all, the problems that are mentioned above, such as flooding, inefficient agricultural operations, and external community-related dangers, cause severe issues to the world, which is the main motivation to look for financially and naturally feasible water release solutions of multiple storage systems in order to provide fresh solutions to these problems.

1.2 Research Objectives

This research aims to develop a real-time integrated low-cost software and hardware system for gravity-driven and remotely-operated water release. The integrated low-cost hardware and software system has been developed for two types of drainage; siphon and conventional drainage pipe. Both types of drainage include liquid water level sensors, PVC pipe, and actuated butterfly valve, while siphon system has additional parts such as air vent, check valve, and bilge pump. This research also evaluates the general cost of the proposed system against the commonly utilized method (SCADA). This research also concentrates on a mathematical analysis for calculating the time-varying flow releases for both types of drainage as well as hydraulic calculation of the proposed system. The analytical equations are validated using the experimental flow release tests.

CHAPTER 2: LITERATURE REVIEW

First of all, the non-renewable aspect of water resources makes it a valuable aspect for the well-being of the habitats, which indicates the need for efficient utilization. Therefore managing water resources is one of the most important wetland conservation methods since the water level is a major contributing factor that affects the general dissociation and biodiversity of aquatic plants in shallow lakes, as well as a pivotal indicator of the lake's hydrological system (Dai et al. 2016).

Apart from natural protection, adjusting water levels can prevent disasters from happening since water release can also be used for flood control by releasing the water level when it reaches the top, i.e., to the maximum level of the storage unit. As stated, reservoir flood protection can be improved by releasing water in order to be able to adapt more appropriately to the imminent, impending flood (Chou and Wu 2013).

In addition to the flood protection, releasing controlled water from restoration reservoirs along with keeping up with the maintenance of downstream can keep the state of the wetland habitats and their livelihoods intact in severe, life-threatening situations. Furthermore, this would allow efficient utilization of wetlands to release water from in accordance with the guidelines from both the Wetland Convention and the Organization for Economic Co-operation and Development (OECD) in 1996 (Acreman et al. 2000).

Another critical problem that needs to be addressed is irrigation which can be highly improved with proper water management. Since irrigation systems have the ability to make drylands available for agricultural process, potential future reservoirs that could be designed for productive purposes such as using the river's energy capacity for power production, reducing the variability of discharge for navigation enhancement, and providing water-related opportunities for the surrounding environment such as irrigation (Biemans et al. 2011).

Since irrigation carries significant importance, there are many variables that need to be considered during the distribution of water for agricultural purposes, which can dramatically decrease the efficiency of the process. In most cases, the level of agricultural production has been significantly lower than its predicted potential due to inefficient irrigation, especially in drought-prone areas. Consequently, the integration of cutting-edge technology with the existing system on the planning and production of reliable water irrigation is imperative (Consoli et al. 2008).

However, a related concern could be planning how to extract and release water that could mitigate ecological and sanitary predicaments due to an inappropriate flow of dynamic combinations and physicochemical water characteristics. Essentially, the whole catchment must be well managed in order to ensure a safe river. In other words, flows cannot be controlled only by strict water reservoir release regulations. Water removals and discharges should also be programmed to minimize any conceivably disastrous environmental and sanitary situations (Nilsson and Renöfält 2008).

One of the approaches to achieve this optimal water release could involve using a coordinated operation of watershed saving implementations such as detention ponds, reservoirs, and wetlands. Moreover, it is evident that conventional storage systems such as detention ponds should be retrofitted (e.g., adding large outflow gates and siphons) in order to obtain a process that is accurately executed, and the outflow structures of these systems should be remotely controlled as a whole using a decision support system (DSS).

The integrated low-cost hardware and software architecture for gravity-driven and remotely operated water release is analogous to that of Supervisory Control and Data

Acquisition (SCADA), which is a control device that is used to monitor, control (manually or automatically), and collect data (Daneels and Salter 1999; Foh and Lee 2004; Goel and Mishra 2009). It primarily consists of three elements which are collection, transmission, and control mechanisms, that work together to operate the entire system. Apart from its technical aspect, the technology is highly popular, and it is one of the most commonly employed methods in the sea industry since it offers real-time data on-field equipment for decision-making from an accessible distance (Gao et al. 2010; Aghenta and Iqbal 2019). According to the researchers, the cost of SCADA systems used by businesses is about $20,000 (Burt and Anderson 2005). It is used in almost every industry, such as power, water storage, drainage, oil/gas processing, and distribution (Gao et al. 2010). Therefore, a new water management approach must provide specific outcomes considering the magnitude of the utilization of conservational methods.

CHAPTER 3: HARDWARE AND SOFTWARE ARCHITECTURE

3.1 Water Management Using Conventional Storage Systems

Conventional storage systems for flood control can be given an example as wetlands, detention ponds, and reservoirs. To start with, wetlands can be identified as an intersection zone in between terrestrial and aquatic ecosystems where the water table is often close to the surface, along with other cases where the land is only cloaked by shallow water (Coughanowr 1998). Wetlands are vital due to their ability to provide certain benefits such as hosting fish and wildlife habitats, enhancement of water quality, recharge of groundwater table, and flood attenuation (Coughanowr 1998; Tsihrintzis et al. 1998; Humid and Coughanowr 1999; Verma 2021). Furthermore, they intercept storm runoff and provide water storage functions in order to reduce flooding risks regardless of the required time period for the storage (Council 1995). Additionally, excessive water caused by extreme rain or melting of snow can be retained by wetlands, allowing more water infiltration into the ground and decreasing downstream of the river flow (Council 2001). However, the major constraint of wetlands is their storage, which is quite limited, decreasing the efficiency of the process (Berlin and Handley 2007). As a result, the storage constraint might enhance the possibility of flooding, especially in cases where the storage is full.

In addition to the wetlands, another type of conventional storage system is a detention pond that can be described as a low-lying area constructed for holding a certain amount of water for a limited time while lightly draining the water to another place. These are usually designed to release the water through an outlet control structure over a period of 2 to 5 days (Bloorchian et al. 2016). Existing detention ponds' outlet control structure could be retrofitted for dynamic storage management by increasing the outlet pipes' diameter and adding actuated gates.

The final type is a reservoir which can be described as natural or artificial storage space for fluids, and it is one of the most frequently used structural means for managing flood events (Guo et al. 2004). A flood mitigation reservoir's basic function is to minimize flood peaks and water surface elevations at downstream locations (Bian et al. 2021). The discharge from a storage reservoir is regulated by outlet gates based on control rules and/or engineers' judgment, making reservoirs more individualized than a systematic method in terms of water management.

Overall, conventional storage systems' outlet structures could be retrofitted (or added in the case of a wetland) to improve flood mitigation. For wetlands, it would be necessary to add controlled siphons or trenched drains with controlled gates. For detention ponds, the retrofitting would include using larger outlet pipes equipped with controlled gates. For reservoirs, retrofitting would include adding gates and the remote operation of the gates. Similar to the case of wetlands, siphons could also be used for detention ponds and reservoirs.

3.1.1 Siphon and Conventional Drainage Pipe System Hardware

As shown in Fig. 1, the remote operation of a network of storage systems can be represented by a four-tier architecture, which is comprised of a decision-support system (DSS)/control software, virtual private network (VPN) router, a programmable logic controller (PLC) and the controlled hardware deployed in the siphon and conventional drainage pipe systems.

The first tier includes DSS and control software. The DSS provides the optimal scheduling for opening and closing the gates for water release applications. This DSS is presented in (Verma et al. 2020).

The control software uses the DSS along with the data acquired by sensors deployed in the field devices to send commands to controlled siphons and gates for their operation. The second tier is a VPN router used to communicate between the DSS/control software and the PLC. This communication utilizes a 4G cellular network (e.g., AT&T). The third tier is PLC, directly connected to the deployed hardware in the field (e.g., level switches, actuated gates). The user/DSS sends commands to each PLC (e.g., open/close outlet valve), which in turn sends a set of commands to the siphon/gates for implementing the order received from the user/DSS (Verma et al. 2020).

Furthermore, the PLC also collects data on the status of sensors. The user would utilize this information for the programming maintenance requirements of the system. The fourth tier consists of the hardware deployed in the storage systems (e.g., wetlands, detention ponds, and reservoirs), such as level switches and actuated gates for the drainage pipe system and level switches, actuated gates, air vents, and pumps for the siphon system.

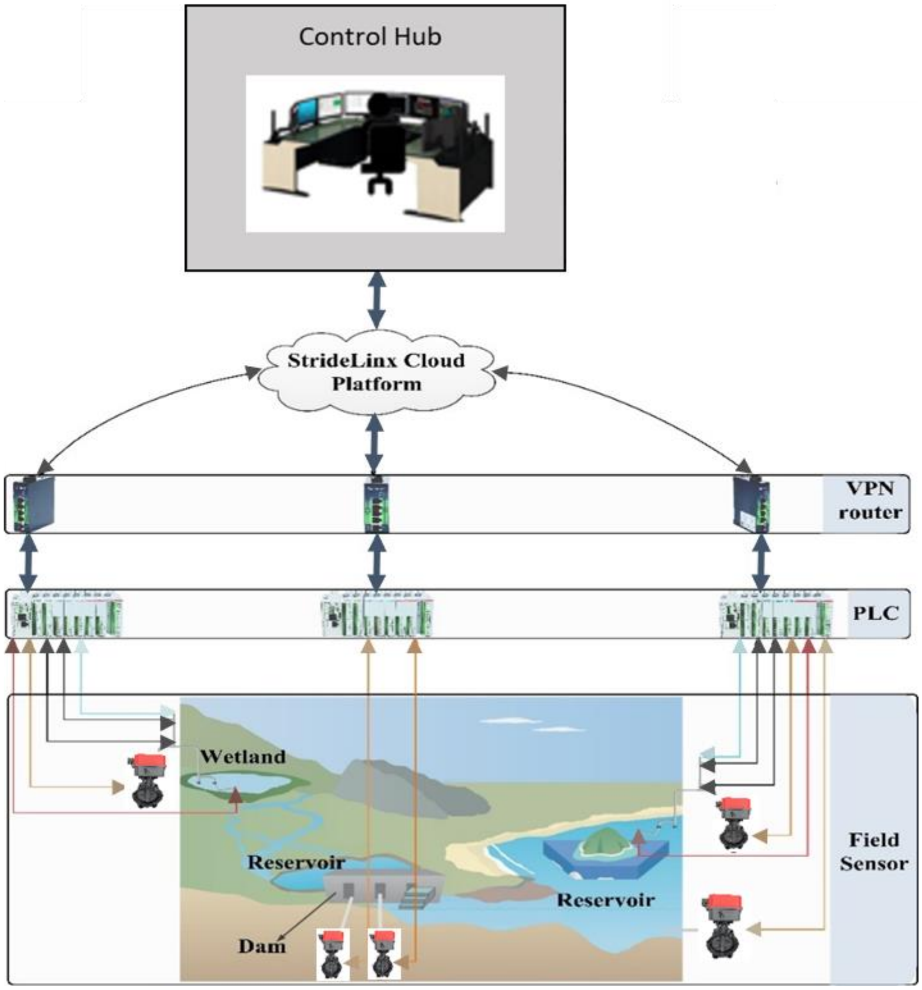

Figure 1: Overview Architecture of Hardware for Remote Operation of a Network of Storage Systems

Fig. 2 illustrates the flowchart employed for decision-making using siphons. All the real-time data is available from sensors employed in the field. Based on rainfall forecasts, inundation scenarios, and the amount of water present in the storage units, the optimization model determines the wetland flow release schedules to minimize flooding. The controlled siphons or trenched drains with controlled gates are operated remotely.

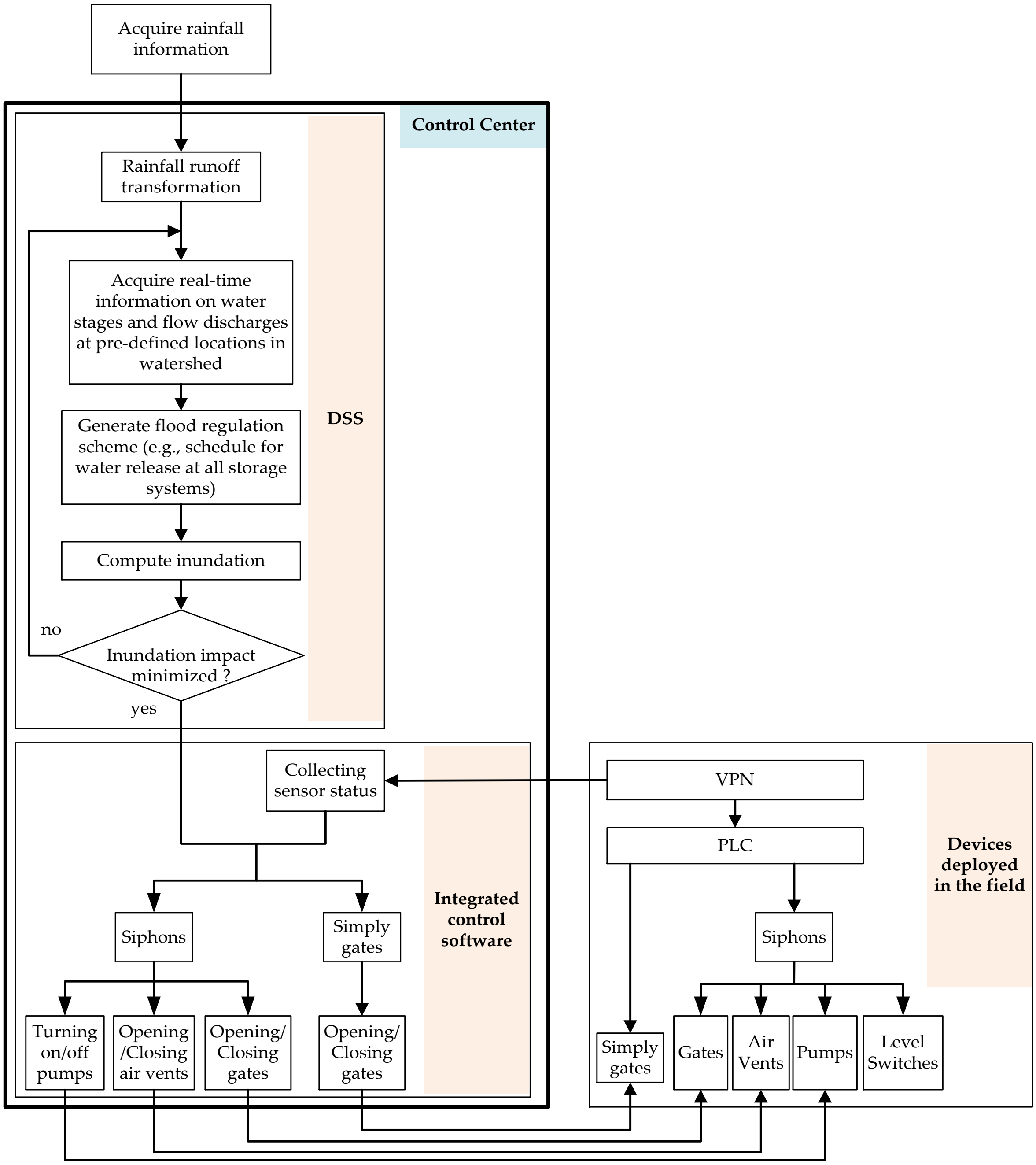

Figure 2: Flowchart of the Decision Making and Flood Control Operation (Qin et al. 2019)

Fig. 3 and Fig. 4 show the siphon and conventional drainage pipes employed to release water from storage units such as reservoirs, wetlands, and detention ponds. Both have an actuated gate installed at the end, which controls the water release from the storage units. Both systems operate under gravity to transfer water from one place to another. An inclined pipe is placed in the field for the conventional drainage pipe system, while in the siphon system, an inverted U-tube structure is placed. The siphon system requires initial priming (e.g., filling of the U-tube pipe). Priming is done with the help of a bilge pump installed in the storage units. The priming is performed with level sensors installed at the siphon pipe's top (sight tube). Thus, the priming process is fully automated.

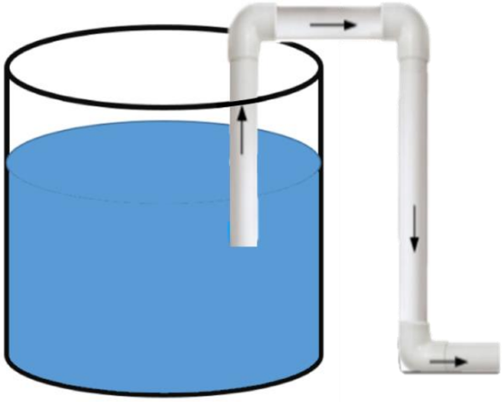

Figure 3: Conventional Siphon System

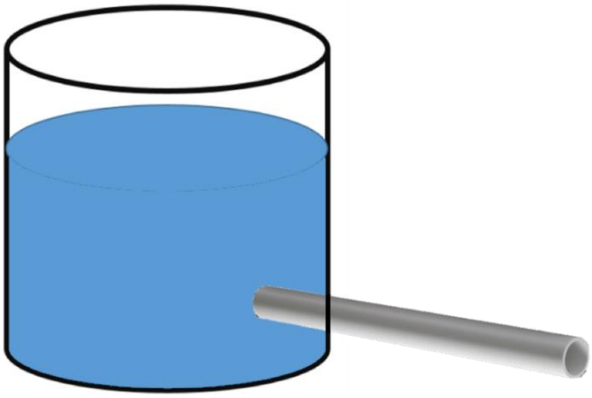

Figure 4: Conventional Drainage Pipe System

3.1.2 Communication

Remote communication in the present study is achieved using 4G cellular technology, which provides benefits of achieving long-range communication, securing data transmissions with security controls, serving the users on an "anytime, anywhere" basis, and better speed (Khan et al. 2009). In this study, the cellular StrideLinx VPN router (SE-SL3011-4G, Automationdirect) shown in Fig. 5 was adopted to establish the connection between the control center and the PLC controller is used for constant secure connection to the StrideLinx server regardless of the location. After connecting VPN to the StrideLinx server network, the user can access the storage systems' hardware through a secure VPN router (Leon and Verma 2019).

Figure 5: The Cellular StrideLinx Router

3.1.3 Programmable Logic Controller (PLC)

Fig. 6 shows a basic structure of PLC, which consists of a central processing unit (CPU), memory, a power supply unit, input/output (I/O) modules, and a programming device (Bayindir and Cetinceviz, 2011).

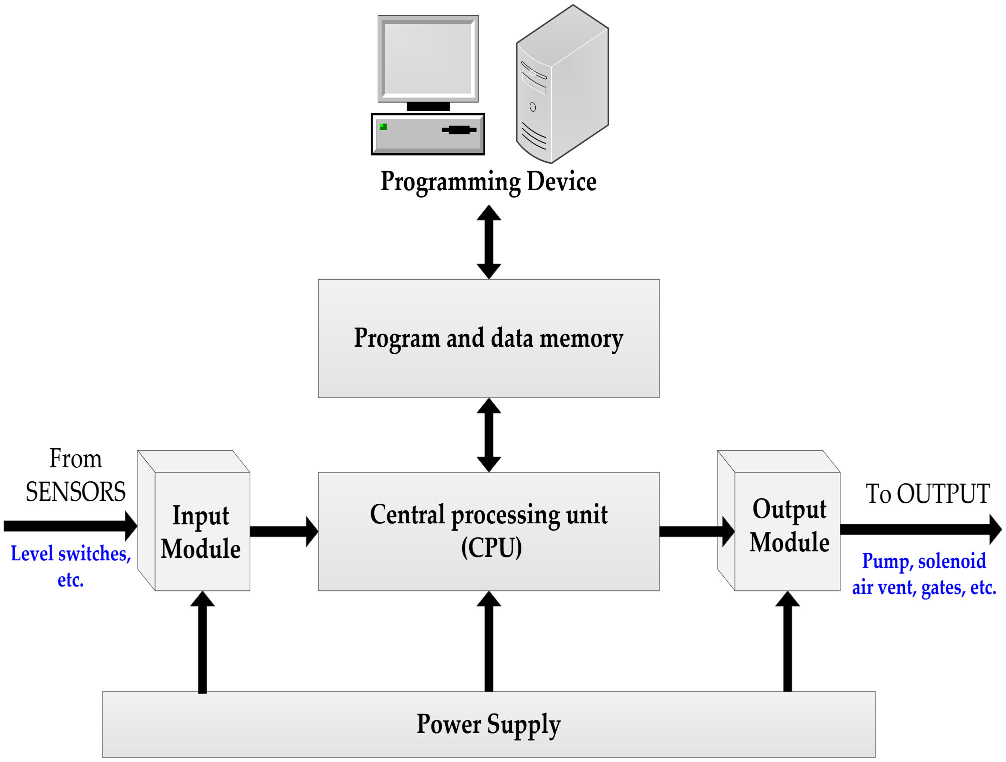

Figure 6: Basic Structure of PLC

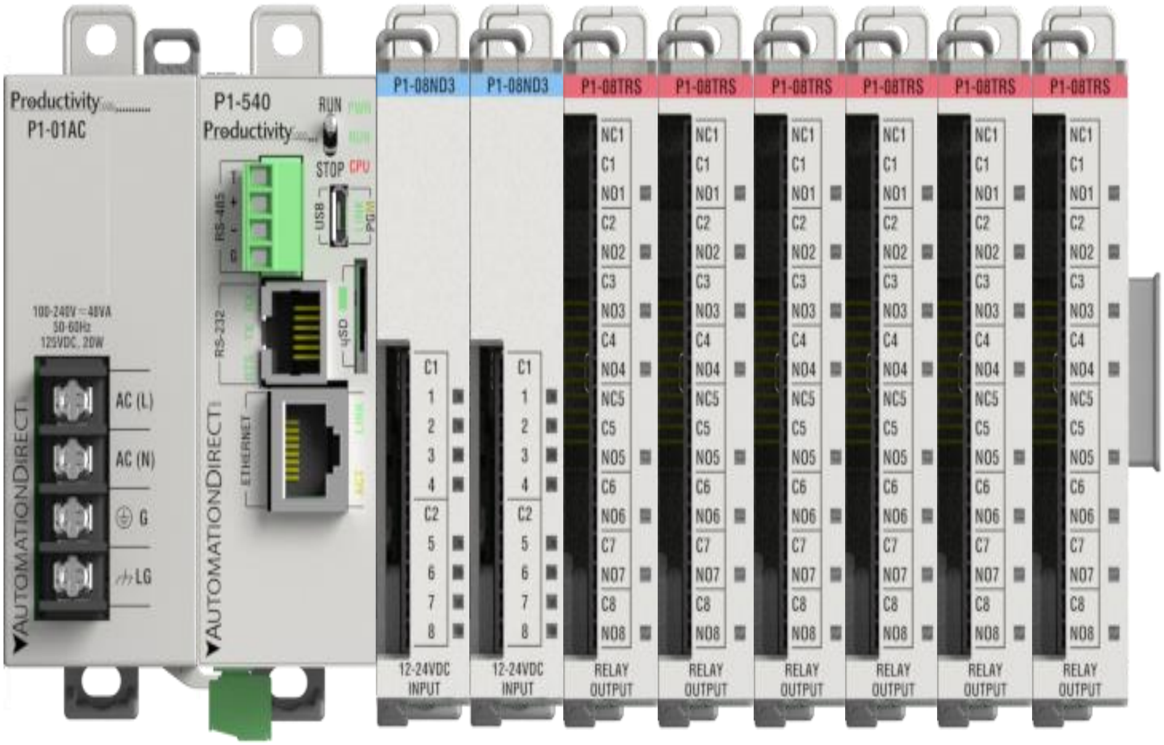

Figure 7: A PLC System for an Array of Actuated Gates

This study used a Productivity 1000 CPU (P1-540), consisting of serial, Ethernet, and micro-B USB ports. The proposed system works under a power supply with 24 VDC (Volts, Direct-Current) ± 2% @ 5W plus 1.25 W per additional I/O module (Qin, Leon, Bian, Dong, Verma and Yolcu, 2019). P1-08ND3 module is a fast response input module that provides eight inputs ranging from 12 to 24 VDC, connecting to level switches in the system. P1-08TRS module is a high-current isolated relay module that provides eight 3A surge-protected outputs for powering actuated gates, air vents, and pumps. Fig. 9 presents a PLC system with 16 discrete inputs and 48 relay outputs, which can connect seven siphons and 18 controlled gates (2 inputs for 2 level switches of the storage system, another 14 inputs for 14 level switches of 7 siphons, 28 outputs for pumps, air vents and gates of 7 siphons, and another 20 outputs for ten actuated gates with no siphon).

Furthermore, each input of productivity 1000 can be easily expanded with up to 128 discrete I/O points. The I/O modules can be easily added or removed using the single latch mechanism on each module's top side.

3.1.4 Power

Solar panels are used for constant recharging of the batteries of the system that all of the hardware components are connected to (e.g., water level sensors, actuated valves, bilge pumps) are connected. Moreover, a Pulse Width Modulation (PWM) charge controller is attached to the solar panel to prevent the backflow of electricity from the battery to the solar panel. Two 12V batteries are employed to power the system because some components such as the bilge pump and air vent use 12V. In contrast, other components such as PLC and the actuated butterfly valves use 24V.

3.2 Software for Controlling an Array of Actuated Gates and Other Devices

The software interface is designed to control the siphon and conventional drainage pipe system. Some features include automatic and/or manual control of both siphon and conventional drainage pipe systems, maintenance/replacement duration of employed hardware in the field, and many more. The developed interface can be used for any number of reservoirs, wetlands, and detention ponds. Each of the storage units can have any number of siphons and conventional drainage pipes. The details about the software interface have been described in the dissertation of Vivek Verma (Verma 2021).

3.3 Integration of Control Software, Communication, and Water Releasing Hardware

Fig. 8 illustrates the schematic of integrating the control software, communication, and the siphon hardware. As shown in Fig. 8, water level sensors, air vent, bilge pump, and actuated butterfly valve are connected to the PLC by a wired connection. The PLC is then connected to the VPN router via an Ethernet port. Finally, the VPN router is connected to the user remotely using a 3G/4G cellular connection. All the components are powered using a battery which is recharged by a solar panel.

The next step is the PLC's collecting all sensor data from the field hardware and transmitting it to the user via a VPN router afterward. The information received by the user is then integrated into the DSS for decision-making. This entire process is automated.

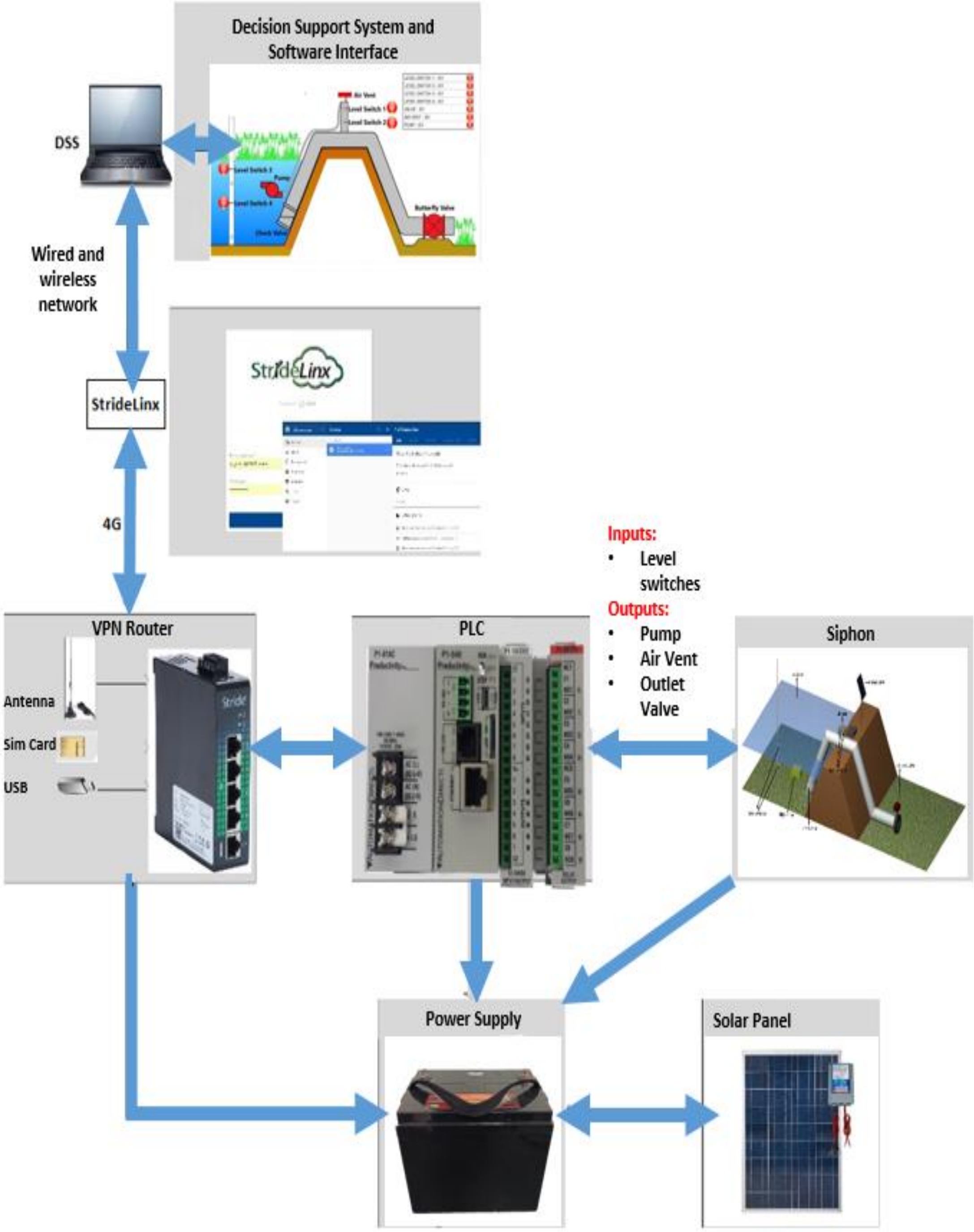

Figure 8: Schematic of the Integration of the Control Software, Communication, and the Siphon Hardware

CHAPTER 4: RESULT AND DISCUSSION

The present chapter demonstrates the results and provides a discussion part about the field setup and performed tests for the proposed controlled siphon and conventional drainage pipe. Several experiments have been performed, and the results are illustrated and discussed in this chapter.

4.1 Field Setup and Experimental Results

4.1.1 Field Setup

Fig. 9 and Fig. 10 show the setup of the conventional drainage pipe and siphon, respectively. The setup was installed at the Florida International University in Miami, Florida. As shown in Fig. 9, the conventional drainage pipe only requires two water level sensors to operate. The top-level is the flooding warning condition (e.g., a pond is almost at maximum level). The bottom one is the empty warning condition (e.g., a pond is at the minimum level to support ecological function). In addition, the actuated butterfly valve is installed at the end of the pipe to regulate the amount of released water. Fig. 10 depicts the controlled siphon system.

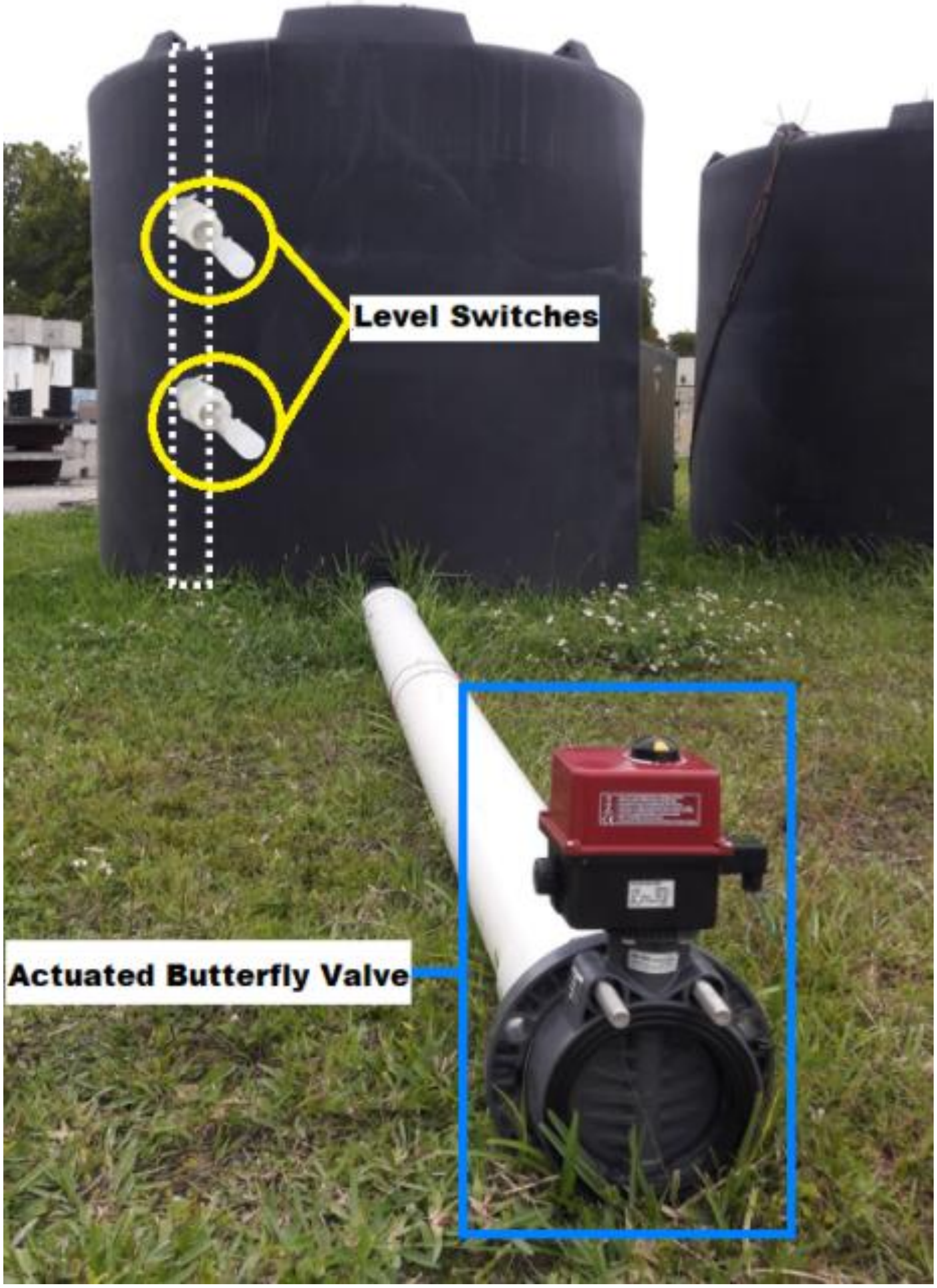

Figure 9: Setup of the Conventional Drainage Pipe System
(Verma et al. 2021)

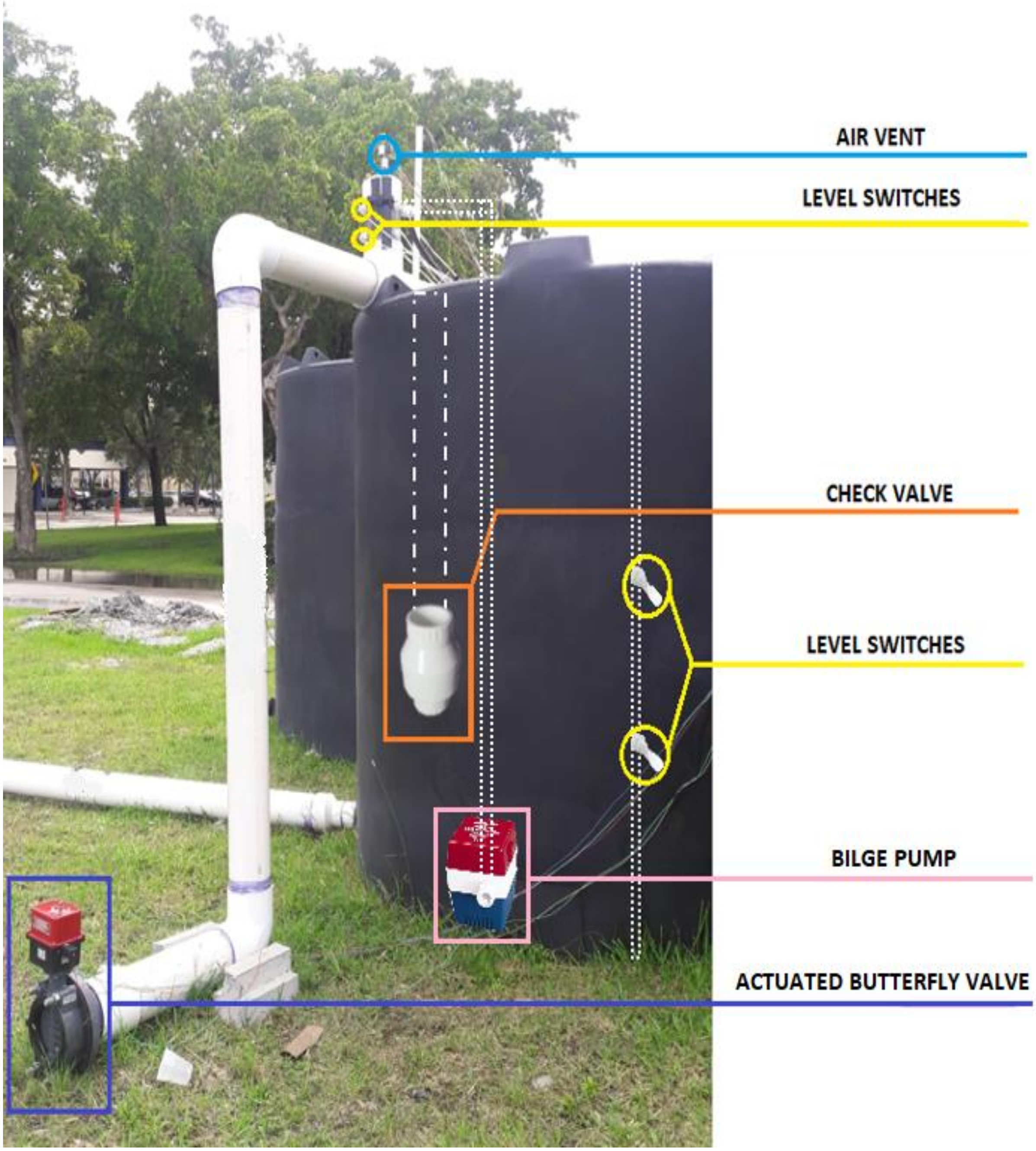

Figure 10: Setup of the Siphon System
(Bian et al. 2021)

Fig. A-1 represents actuated ball valve that has been installed in the field to perform siphon experiments. Similarly, Fig. A-2 represents actuated butterfly valve that has been installed in the field to perform the siphon and conventional drainage pipe system experiments. Fig A-1 and Fig. A-2 are given in Appendix A. The difference between the two ball valves is that the amount of time taken to open and close the ball valve completely. The actuated ball valve is slow, and hence it takes more time to operate than actuated butterfly valve.

Fig. A-3 illustrates Data Acquisition System, which is given in Appendix A. As the name suggests, it acquires all the data that has been performed during the siphon or conventional drainage pipe system experiment. The data includes a hydrograph that indicates the date of discharge vs. time plot and water depth vs. time plot and data obtained from the flowmeter shown in Fig. 12. The horizontal axis represents time. The vertical axis represents discharge and water depth on the right and left sides of the vertical axis, respectively, in the siphon experiment that has been shown in the next section.

Flowmeter in Fig. A-4 measures the amount of water flowing through the pipe in a given interval of time. It consists of transducers tied together on the circumference of the PVC pipe with the help of rope. First, lubricants are applied to transducers, and then they are placed on the PVC pipe. This lubricant increases the sensitivity of the flow meter, which increases the accuracy of the obtained data.

The water level sensor that is given in Fig. A-5 is installed in a vertical pipe and placed near the top of the water tank that has the capacity of 2,000 gallons. The water level sensor provides real-time data as a function of the depth of water vs. time. It requires calibration, which mainly involves the tank's dimensions, length, width, and height. Fig. A-5 is shown in Appendix A.

4.1.2 Calibration of the Water Level Sensor and Flowmeter

A water level sensor is utilized to assess the water level in the water tank, while the flow meter is used to measure discharge. Both instruments are calibrated using NiDAQ hardware, and the values were collected in the LabView software program.

The water is filled to the maximum level of the container without exceeding the 20mA level in order to obtain a proper calibration from the water level sensor. Then, water is released from the container, and the corresponding value of current is recorded. The range of the electricity was between 4mA to 20 mA. After getting the value of current as a function of water level depth, LabView frame is created for measuring the water level depth in the water tank.

Flowmeter consists of transducers tied together on the outer circumference of the PVC pipe with the help of rope. Lubricants, which increase the flow meter's sensitivity to obtain more accurate data, are applied to transducers and then tied with the PVC pipe.

Flowmeter data is extracted by using the current from 4mA to 20mA for the LabView. Since the flowmeter has a wired connection to receive currents using NiDAQ, LabView receives the signal by releasing water, and then the collected readings of currents based on the discharge data are then transformed from regression analysis. The complete process is illustrated in Fig. 11.

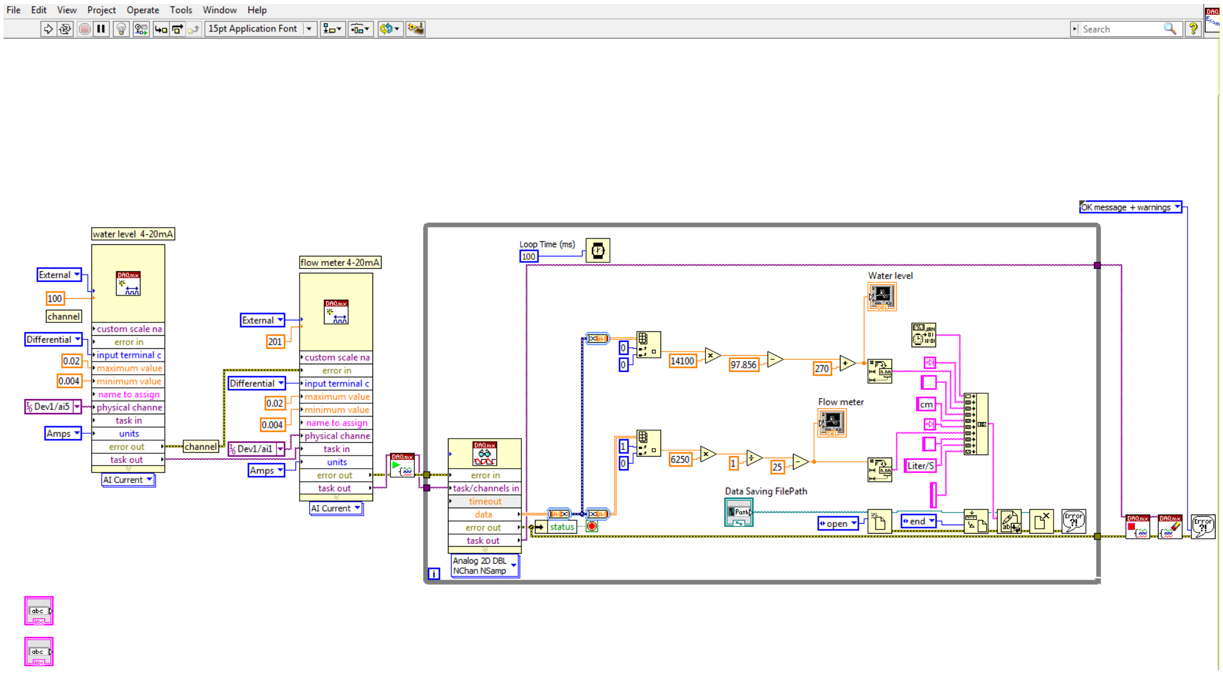

Figure 11: LabView Frame Illustration

Once the water level sensor and flowmeter are set in the LabView, the NiDAQ reads the data and reflects the real-time readings of the water level sensor and flowmeter, as shown in Fig. 12.

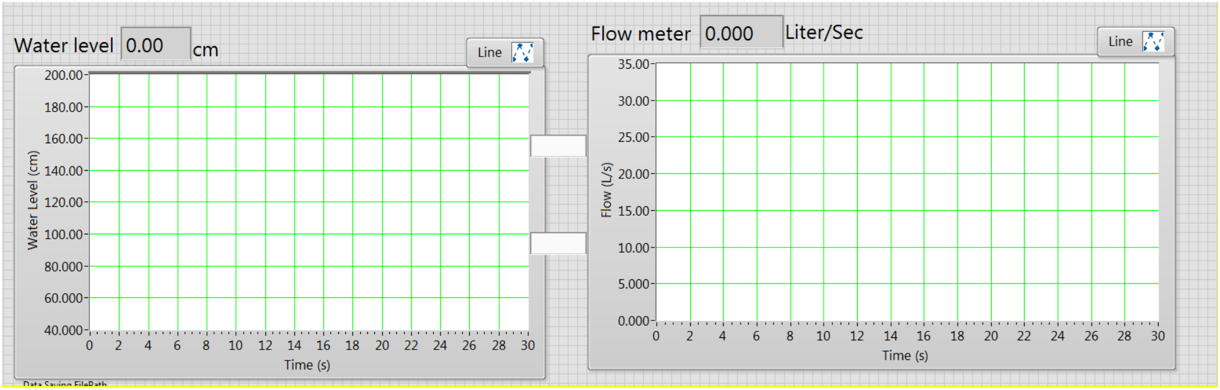

Figure 12: LabView Data Read for Water Level and Flow Meter (Discharge)

4.1.3 Experimental Results

Various experiments have been performed for the controlled siphon and the conventional drainage pipe system. Fig. 13, Fig. 14, and Fig. 15 show the results of a water release test for the siphon system. Fig. 16 and Fig. 17 show the results of a water release test for the conventional drainage pipe system. In these figures, the horizontal axis denotes time in seconds, the left y-axis denotes water level in cm, and the right y-axis denotes discharge in Liters/second. Thus, the blue curve in these curves depicts a water level trace, while the red curve depicts the flow discharge trace.

The water release for the siphon system with actuated ball valve (Fig. 13) starts at about 180 seconds as the system is primed before releasing water and the water release for the siphon system with actuated butterfly valve (Fig. 14 and Fig. 15) starts at about 35 seconds as the system is primed before releasing water. The water release for the conventional drainage pipe (Fig. 16 and Fig. 17) starts at about 25 seconds as no priming is required for this flow release.

Two types of valves are used in the study. One is an actuated ball valve, and the other is an actuated butterfly valve. The actuated ball valve takes a longer time to open and close than the actuated butterfly valve. The actuated ball valve is installed in the siphon system, and the actuated butterfly valve is installed in the conventional drainage pipe system.

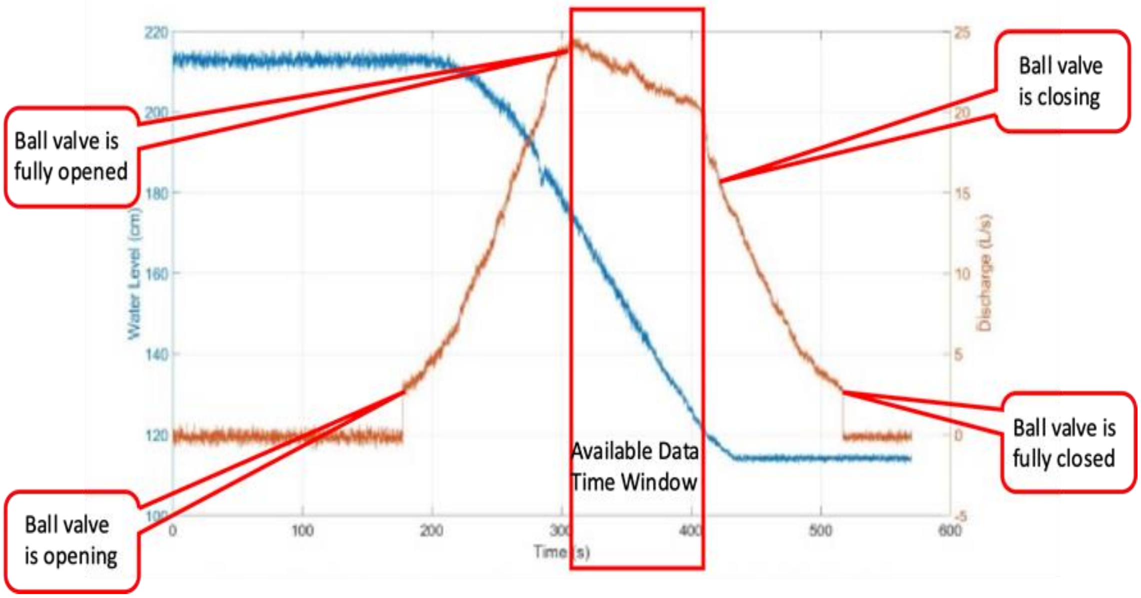

Figure 13: Experimental Result for Siphon System (6-inch Diameter Actuated Ball Valve)

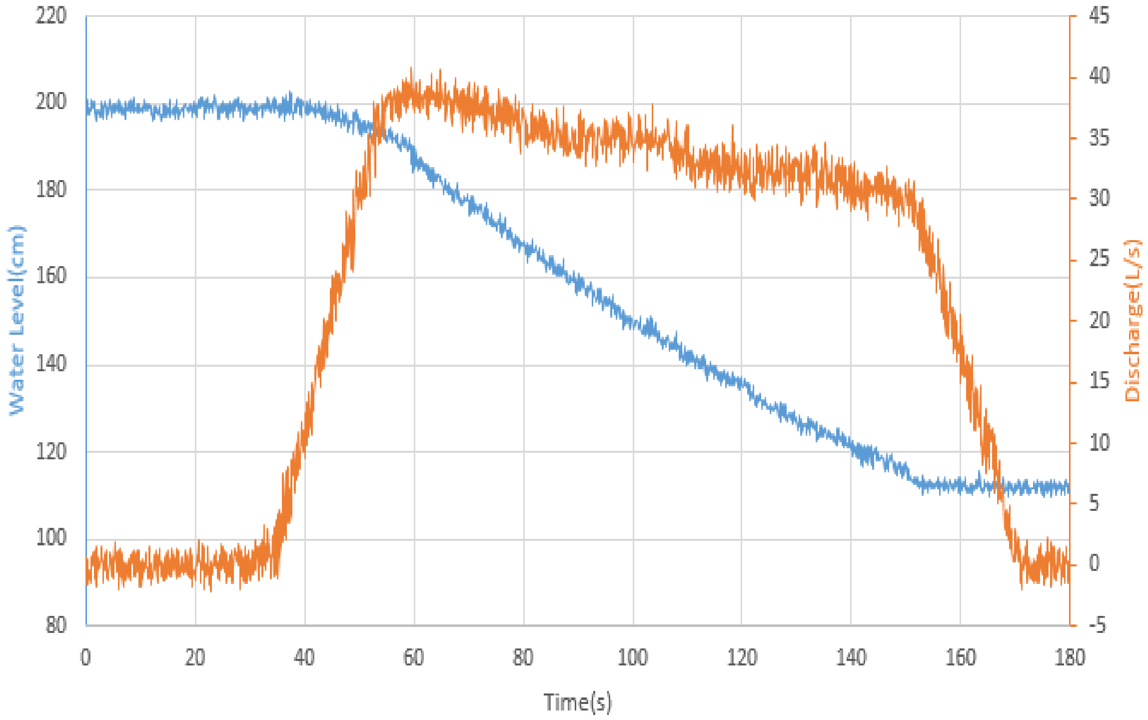

Figure 14: Experiment No.1 Result for Controlled Siphon System (6-inch Diameter Actuated Butterfly Valve)

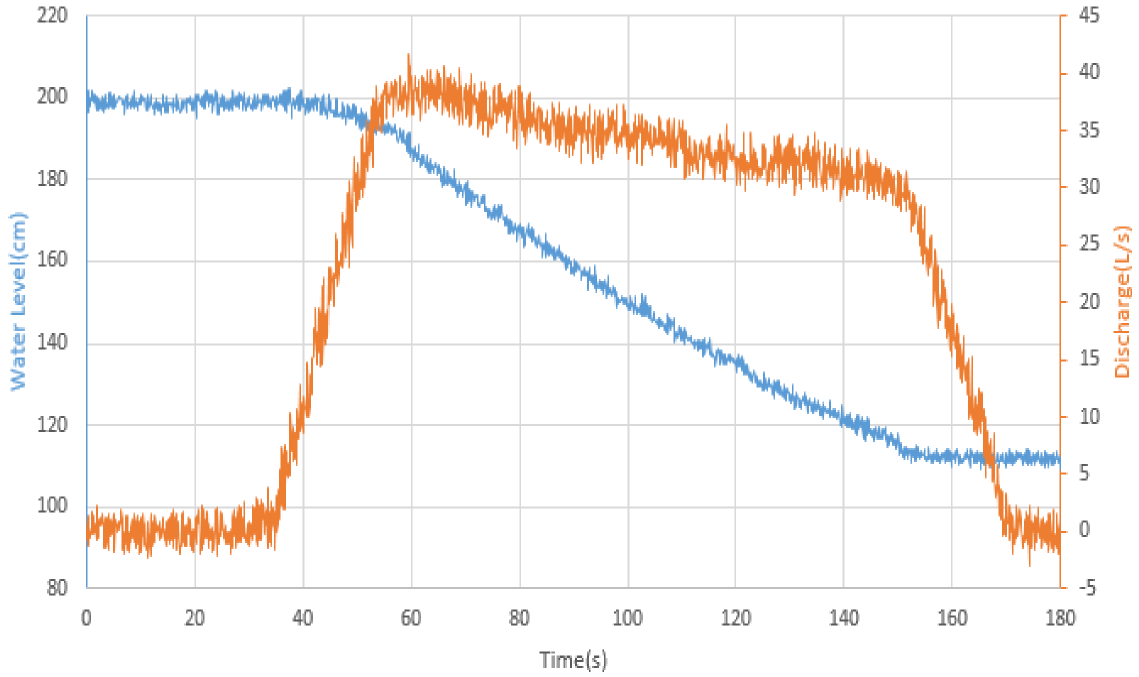

Figure 15: Experiment No.2 Result for Controlled Siphon System (6-inch Diameter Actuated Butterfly Valve)

Fig. 13 illustrates the hydrograph in which a sharp jump is observed. The result of the jumps is because of the slow opening of the actuated ball valve.

Fig. 14 shows the hydrograph in which no jump is observed. In this experiment, the actuated ball valve was replaced with a butterfly ball valve, which operates more smoothly than an actuated ball valve. Hence, the graph becomes more continuous, and no sharp jump is observed.

Several experiments have been performed using the proposed siphon system, and the results are given in Fig. 14 and Fig. 15. Water is transferred from the water tank that acts as a storage unit of 2,000 gallons to the outside. The siphon system should be primed before it can be operated. This priming is performed using a bilge pump and air vent, and the entire system is automated. Water travels from an inverted U tube because of negative pressure. The water level measurement has been performed using two liquid level switches placed at a distance of 200 cm and 110 cm from the ground, respectively. The flow has been measured using a flow meter that was installed near the butterfly ball valve. All the hardware components were connected to Data Acquisition System to record the readings. All of the experiments that are mentioned above signify that the experiments can be repeated as they produce the approximately same results.

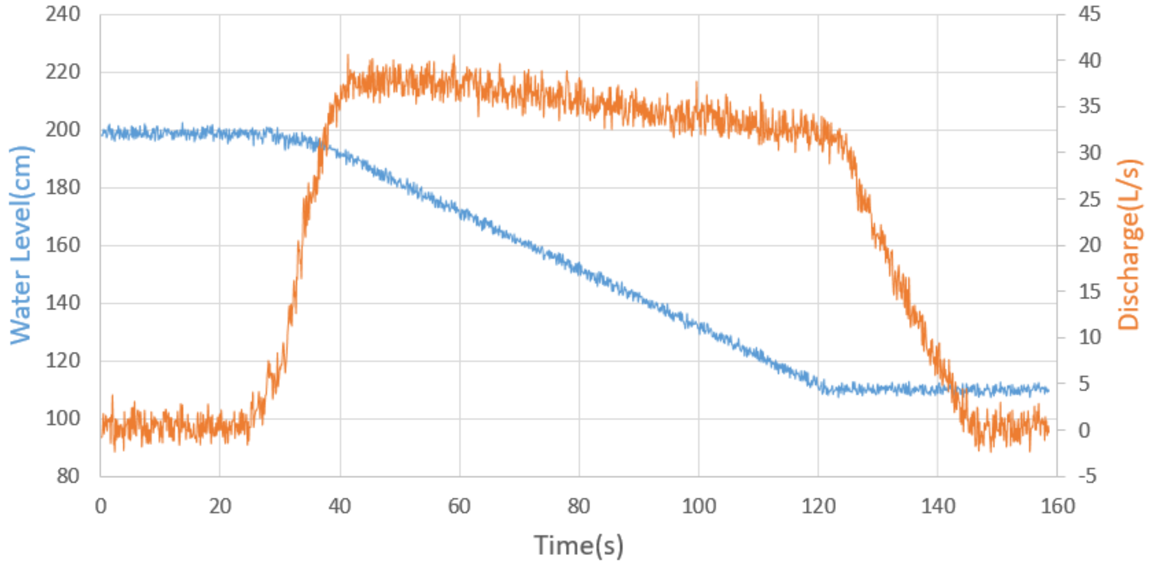

Figure 16: Experimental No.1 Result for Conventional Drainage Pipe System (6-inch Diameter Actuated Butterfly Valve)

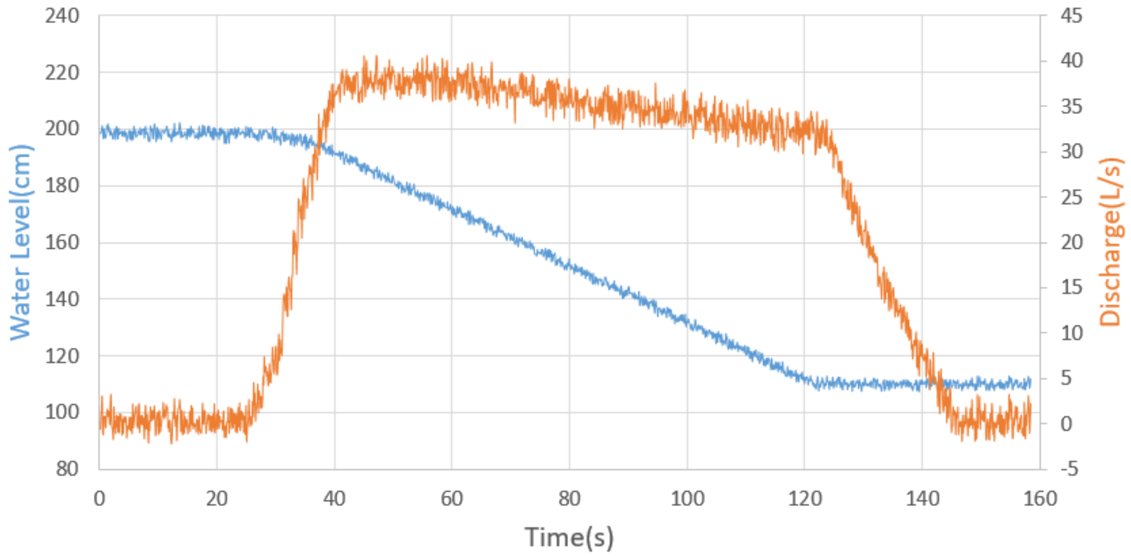

Figure 17: Experiment No.2 Result for Conventional Drainage Pipe System (6-inch Diameter Actuated Butterfly Valve)

Once the setup is established in the field, several experiments have been performed using a water tank of 2,000 gallons of a conventional drainage pipe system, and the results are given in Fig. 16 and Fig. 17. The water is transferred with the help of a sloped pipe that is attached to the water tank. The water tank acts as a storage unit in this experiment. The water level measurement has been performed using two liquid level switches placed at a distance of 200 cm and 110 cm from the ground, respectively. The flow meter is used to measure the discharge from the sloped pipe, and it is placed near the end of the sloped pipe to provide an accurate reading. The flow meter is connected to the Data Acquisition System, and the readings were recorded automatically as soon as the experiment started. The results from the graphs signify that the experiments are repeatable as they represent almost the same hydrograph.

Table 1 and Table 2 show the water level conditions as measured from the ground in the water tank, which has a capacity of 2,000 gallons are given below.

Table 1: Water Level Conditions 6-inch Conventional Drainage Pipe System Experiment with Actuated Butterfly Valve

CONVENTIONAL DRAINAGE PIPE SYSTEM EXPERIMENT		
Experiment No	Water Level at Switch 3(cm)	Water Level at Switch 4(cm)
1	200	110
2	200	110

Table 2: Water Level Conditions of 6-inch Siphon Experiment with Actuated Butterfly Valve

CONTROLLED SIPHON SYSTEM EXPERIMENT		
Experiment No	Water Level at Switch 3(cm)	Water Level at Switch 4(cm)
1	200	110
2	200	110

Experimental result comparison between the siphon and conventional drainage pipe system is given in Fig. 18. The blue color represents the siphon system, and the red color represents the conventional drainage system. The dashed blue window shows the available data for the siphon system, and the dashed red window shows the available data for the conventional drainage pipe system. The experiments are conducted in the same water level conditions. Therefore, conventional drainage pipe and siphon system experiment results are combined. It can be concluded that the conventional drainage pipe system has slightly more flow than the siphon system under the same condition.

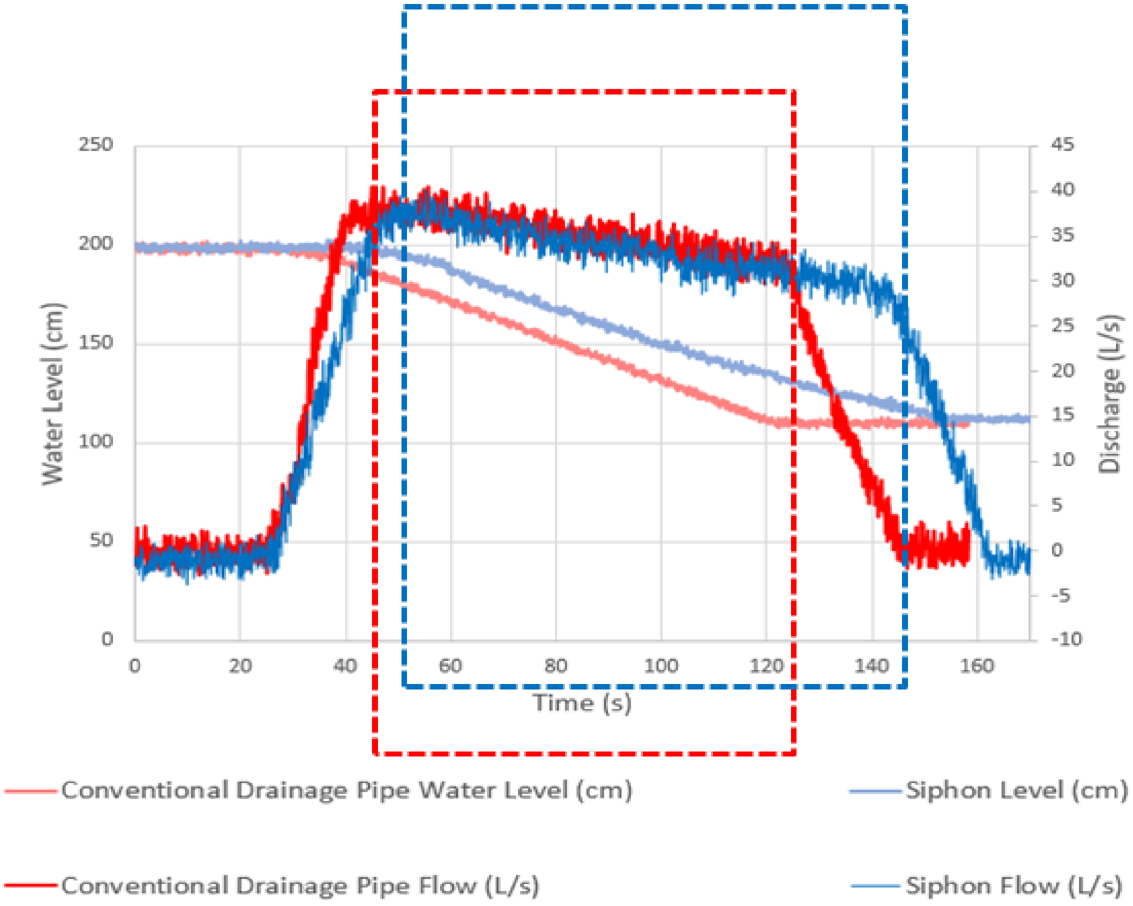

Figure 18: Siphon and Conventional Drainage Pipe System Experimental Result Comparison under the Same Water Level Conditions

Based on the experimental result in Table 3, a comparison between the discharges of two systems is given in certain water levels of 140 cm, 160 cm, and 180 cm, respectively. This comparison between the siphon and conventional drainage pipe system expresses that the conventional drainage pipe system has slightly more flow than the siphon system.

Table 3: Comparison Between Siphon and Conventional Drainage Pipe System under the Different Water Levels

Water Level (cm)	Siphon Discharge (L/s)	Conventional Drainage Pipe Discharge (L/s)
140	32.5 （±0.1）	35.0 （±0.2）
160	35.0 （±0.3）	36.5 （±0.2）
180	37.5 （±0.2）	38.7 （±0.1）

4.2 Analytical Analysis of the Siphon and the Conventional Pipe System

A full energy equation can be used to analyze flow releases. The full energy equation is shown below;

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_f + h_l \qquad Eq.1$$

where, Z_1 and Z_2 are upstream and downstream elevation, P_1 and P_2 are upstream and downstream pressure, V_1 and V_2 are the upstream and downstream velocity, respectively. γ is the specific weight of water, g is the gravity, h_f is the total friction head loss and h_l is the local head losses.

Velocity head is neglected, and Eq. 1 can be rewritten as below;

$$Z_1 - Z_2 = \frac{V_2^2}{2g} + h_f + h_l \qquad Eq.2$$

Therefore, the velocity in the outlet can be simplified as;

$$V = \sqrt{2g(Z_1 - Z_2) - (h_f + h_l)} \qquad Eq.3$$

Darcy-Weisbach formula is used to approximate the friction losses;

$$h_f = \frac{fLV^2}{2gD} \qquad Eq.4$$

L is the length of the pipe, f is a dimensionless friction factor, V is the average velocity, and D is the pipe diameter. Reynolds number and the relative roughness of the pipe is the function of the friction factor. The Haaland equation is used to calculate the f;

$$\frac{1}{\sqrt{f}} = -1.8log_{10}\left[\left(\frac{\varepsilon}{3.7D}\right)^{1.11} + \left(\frac{6.9}{R_e}\right)\right] \qquad Eq.5$$

where, R_e is the Reynolds number, ε is the roughness height, D is the diameter of the pipe. Total local head losses h_l is illustrated below;

$$h_l = \sum k_i\left(\frac{V^2}{2g}\right) \qquad Eq.6$$

where k coefficient of dimensionless head loss for the pipe fitting. Table 4 shows the k values of selected components for the siphon system.

Table 4: Values of k for the Selected Components (Drainage Pipe Systems) (Larock et al. 2000)

Component	k values
Medium radius elbow (90°)	0.7
Pipe entrance (Square-edged)	0.5
Swing Check Valve	2.3
Butterfly Ball Valve (fully open)	0.4

The proposed drainage systems are analytically analyzed in the following. Pipe flow occurs when water flows fully within a close conduit. It is no doubt that the flow caused by siphon pipe and conventional drainage pipe is a typical pipe flow. The friction head loss (h_f) is negligible as the length of the conventional drainage and siphon pipe is 3m. Since the maximum pipe length in our experiment is not over 5m, only the local head (h_l) is considered during the flow calculation and experiment result analysis.

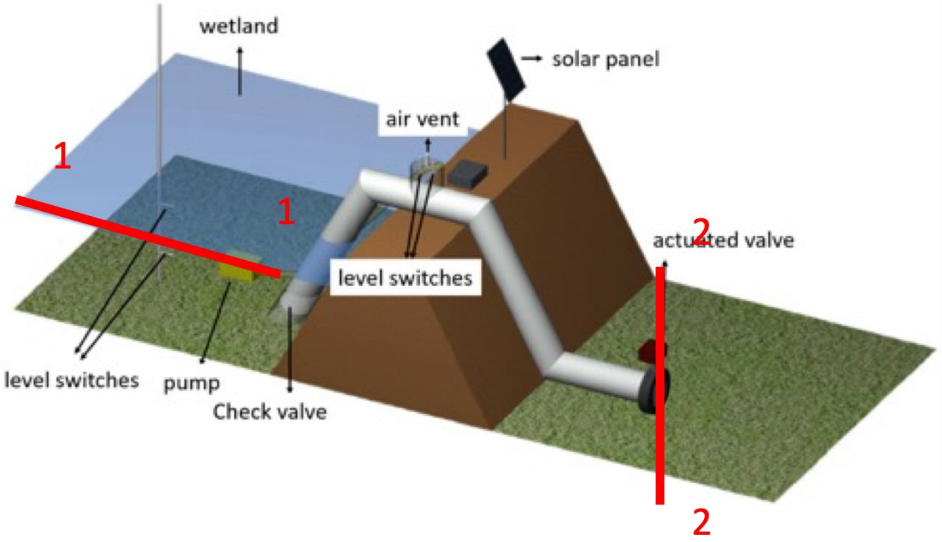

Figure 19: AutoCAD Sketch of Siphon

As shown in Fig. 19, taking siphon as an example, and the outlet of the siphon pipe is not submerged under the water.

The flow should meet the continuity equation, as shown in Eq. 7;

$$A_1 v_1 = A_2 v_2 \qquad Eq.7$$

The flow should meet the energy equation at the 1-1 and 2-2 cross-sections, which is shown as Eq. 8;

$$Z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + h_l \qquad Eq.8$$

The local head loss can be expressed as Eq. 9 and Eq.10 below;

$$h_l = \sum k \frac{v^2}{2g} \qquad Eq.9$$

$$h_f = f \frac{L}{D} \frac{v^2}{2g} \qquad Eq.10$$

where k is the local head loss coefficient, and f is a friction loss coefficient.

From Eq. 7 to Eq. 10, the velocity (v) and discharge (Q) as a function of water depth (H) can be derived as Eq. 11 and Eq. 12 below;

$$v = \left(\frac{2gH}{1 + \sum k + f\frac{L}{D}}\right)^{\frac{1}{2}} \qquad Eq. 11$$

$$Q = v \times A = \frac{1}{4}\pi D^2 \times \left(\frac{2gH}{1 + \sum k + f\frac{L}{D}}\right)^{\frac{1}{2}} \qquad Eq. 12$$

In order to analyze the experiment results, we need to develop the analytical equation to describe the water depth (H) as the function of time (T). As shown in the figure below, when pipe drains the water from the tank, the volume that decreases inside the water tank should be equal to the volume that flows out of the water tank.

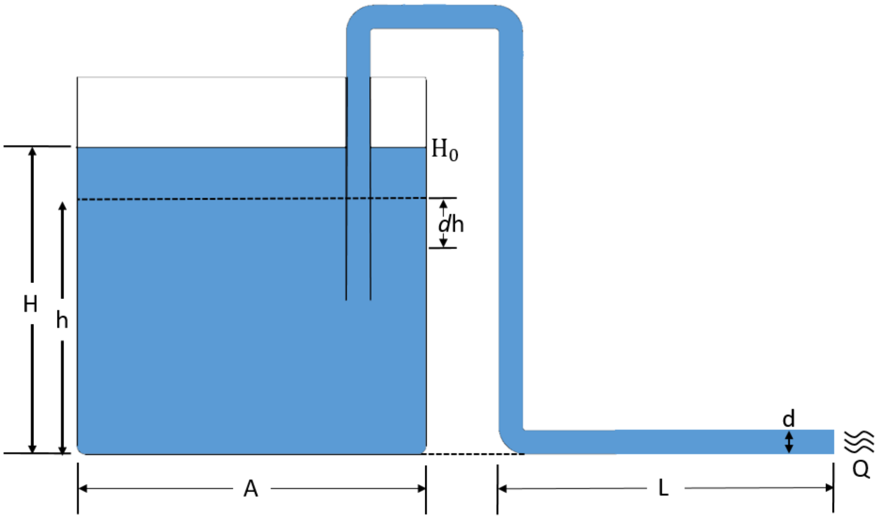

Figure 20: Side View of Water Tank with Siphon

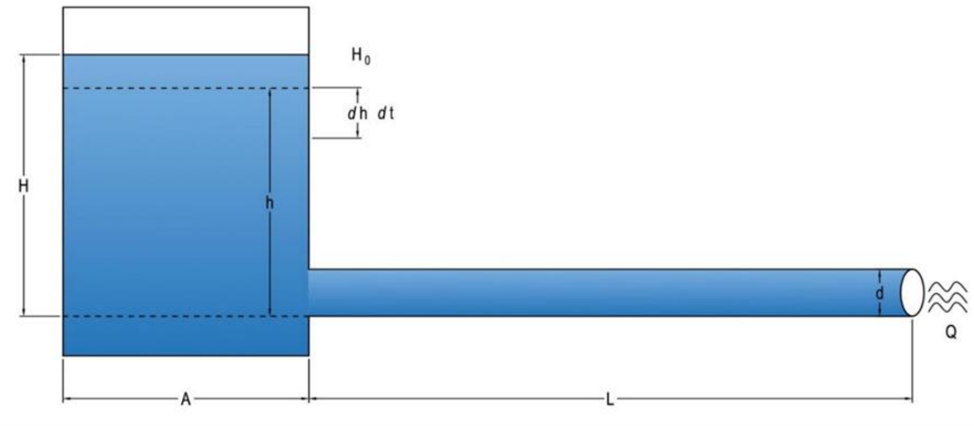

Figure 21: Side View of Water Tank with Conventional Drainage Pipe

Therefore, within an infinitesimal time interval(dt), the water volume decreased in the tank, and the water volume flow outside of the tank should meet the relationship as shown in Eq. 13;

$$dV = Q(h)dt = \frac{1}{4}\pi D^2 \times \left(\frac{2g}{1 + \sum k + f\frac{L}{D}}\right)^{\frac{1}{2}} \sqrt{h} \times dt \qquad Eq. 13$$

where dV also can be expressed as the Eq. 14 below;

$$-dV = A \times (dh) \qquad Eq. 14$$

where A is the base area of the tank and dV is the water volume decreased in the tank, and dh is the water level decreased in the tank.

From Eq. 13 to Eq.14, the differential equation which is described the relationship between time (t) and the water depth (h) is shown as Eq. 15 below;

$$\int_0^T dt = -\sigma \int_{H_0}^{H} \frac{1}{\sqrt{h}} dh \qquad Eq. 15$$

where, σ is all the constant parameters that are extracted from Eq. 13. σ is fully expressed in Eq. 16.

$$\sigma = \frac{A}{\frac{1}{4}\pi D^2 \times \left(\frac{2g}{1 + \sum k + f\frac{L}{D}}\right)^{\frac{1}{2}}} \qquad Eq. 16$$

Haaland equation is used to determine the friction for a 6-inch PVC pipe. The plot is shown in Fig. 22.

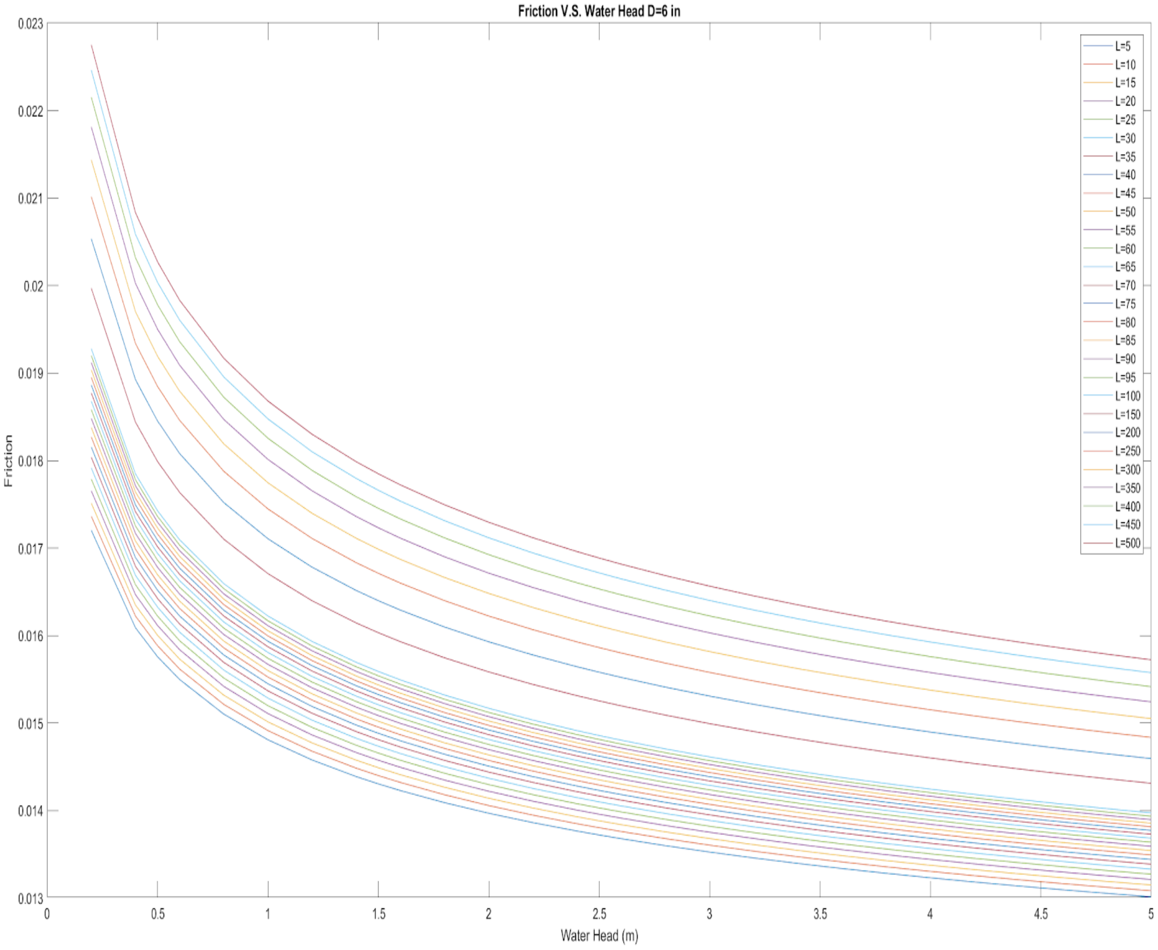

Figure 22: Friction Loss Coefficient as a Function of Water Head under 6-inch PVC Pipe Diameter

The friction loss coefficient (f) is assumed constant during the releasing process based on Fig. 22, a friction loss coefficient as a function of water head under 6-inch PVC pipe diameter.

$$T = 2\sigma \int_{H_0}^{H} d\sqrt{h} = 2\sigma\sqrt{h}\,\Big|_{H_0}^{H} = 2\sigma\left(\sqrt{H_0} - \sqrt{H}\right) \qquad Eq. 17$$

Then transforming the above equation to has a function of t;

$$h(t) = \frac{1}{4\sigma^2}t^2 - \frac{\sqrt{H_0}}{\sigma}t + H_0 \ \ (parabolic\ eq) \qquad Eq. 18$$

where H_0 is the initial water depth in the tank, and $h(t)$ is the water depth at a given time.

From Eq. 9, Eq. 19 can be derived as below;

$$\sqrt{H} = \frac{1}{\sqrt{\dfrac{2g}{1 + \sum k + f\dfrac{L}{D}}}}v \qquad Eq. 19$$

Combining Eq. 17 and Eq. 19, the discharge as a function of time can be derived as shown in Eq. 20;

$$T = 2\sigma \int_{H_0}^{H} d\sqrt{h} = 2\sigma\sqrt{h}\,\Big|_{H_0}^{H} = 2\sigma\left(\sqrt{H_0} - \frac{1}{\sqrt{\dfrac{2g}{1 + \sum k + f\dfrac{L}{D}}}}v\right) \qquad Eq. 20$$

Therefore, transforming Eq. 20 into Eq. 21, which is the velocity as a function of time as shown below;

$$v = -\frac{\pi D^2}{4A}\left(\frac{2g}{1 + \sum k}\right)t + \sqrt{\frac{2g}{1 + \sum k + f\dfrac{L}{D}}}\sqrt{H_0} \qquad Eq. 21$$

Discharge results can be found as shown in Eq. 22, where the A_d is the cross-section area of the proposed systems;

$$Q = A_d \times v \qquad Eq.22$$

The difference between the siphon system and the conventional pipe system is the local head loss coefficient (k). The siphon includes three flanged elbows 90°, a swing check valve, and a butterfly valve, whereas the conventional drainage pipe only consists of a butterfly valve. Therefore, the total k value is 5.3 for the siphon and 0.9 for the conventional pipe, according to Table 4, where the k values for the selected components are given.

4.3 Hydraulic Performance of Siphon and Conventional Drainage Pipe System

In order to see the hydraulic performance of the siphon and conventional drainage pipe systems, the analytical calculations were conducted using Matlab. The water tank demonstrated in the experiment has 4.1m^2 occupied area. The pipe size for constructing the siphon and the conventional drainage pipe is 6-inch (0.15 m) diameter. The initial water depth in the tank was set to 200 cm, and the minimum water depth was set to 110 cm for the analytical calculations since the water level switches inside of the water tank for the experiment were set closer to 200 cm and 110 cm, respectively.

Fig. 22 shows the variation of friction factor with respect to water head for various pipe lengths. The friction factor varies in the range of 0.0147-0.0139 for water head drop from 1.8 to 1.1 meter, where the available data window is shown. Based on the friction factor range, an average value of 0.0143 was selected for the analytical equation.

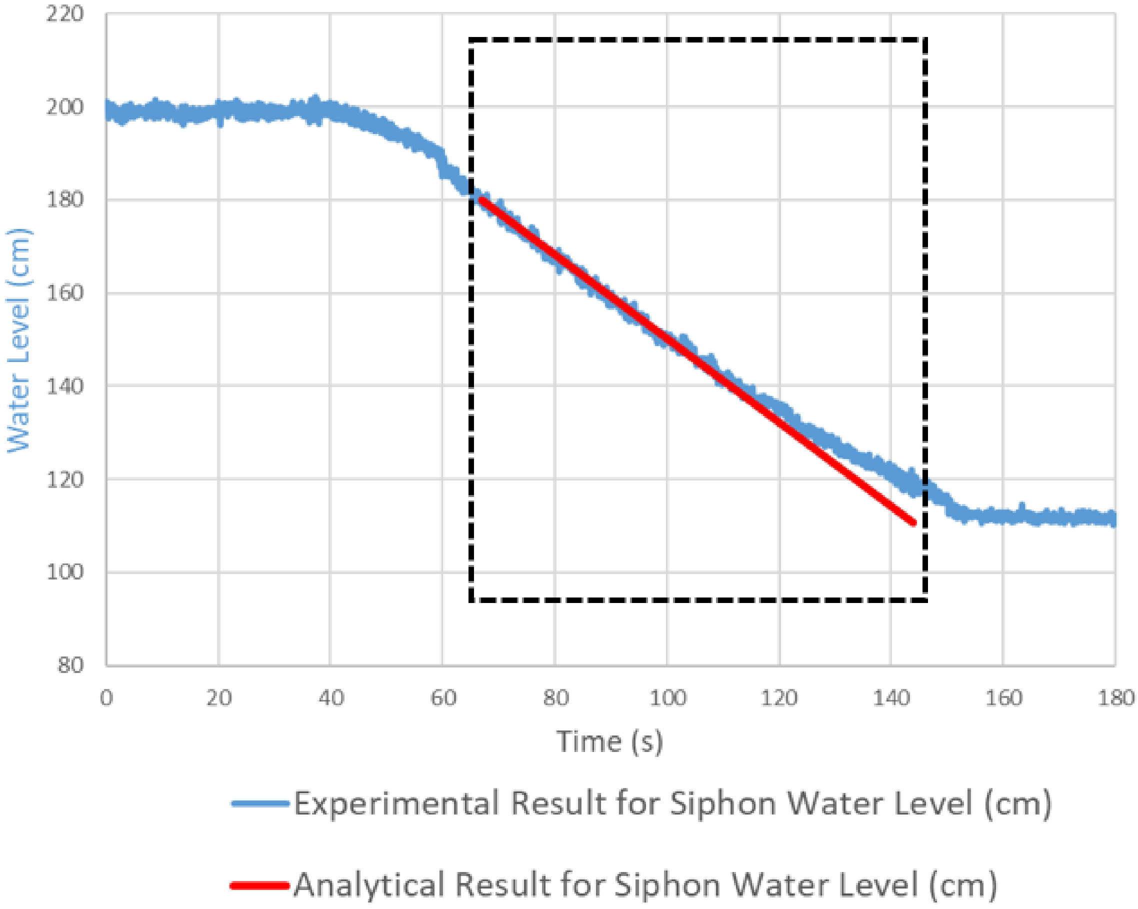

Figure 23: Comparison of the Experimental and Analytical Result (Eq. 18) for the Siphon System

The experimental result is validated with the analytical result of the proposed systems in Fig. 23 for the siphon system and Fig. 24 for the conventional drainage pipe system. The Black dashed window represents the available data window. Matlab is used to compare the analytical result with the experiment result. The initial water depth is set to 180 cm for analytical analysis.

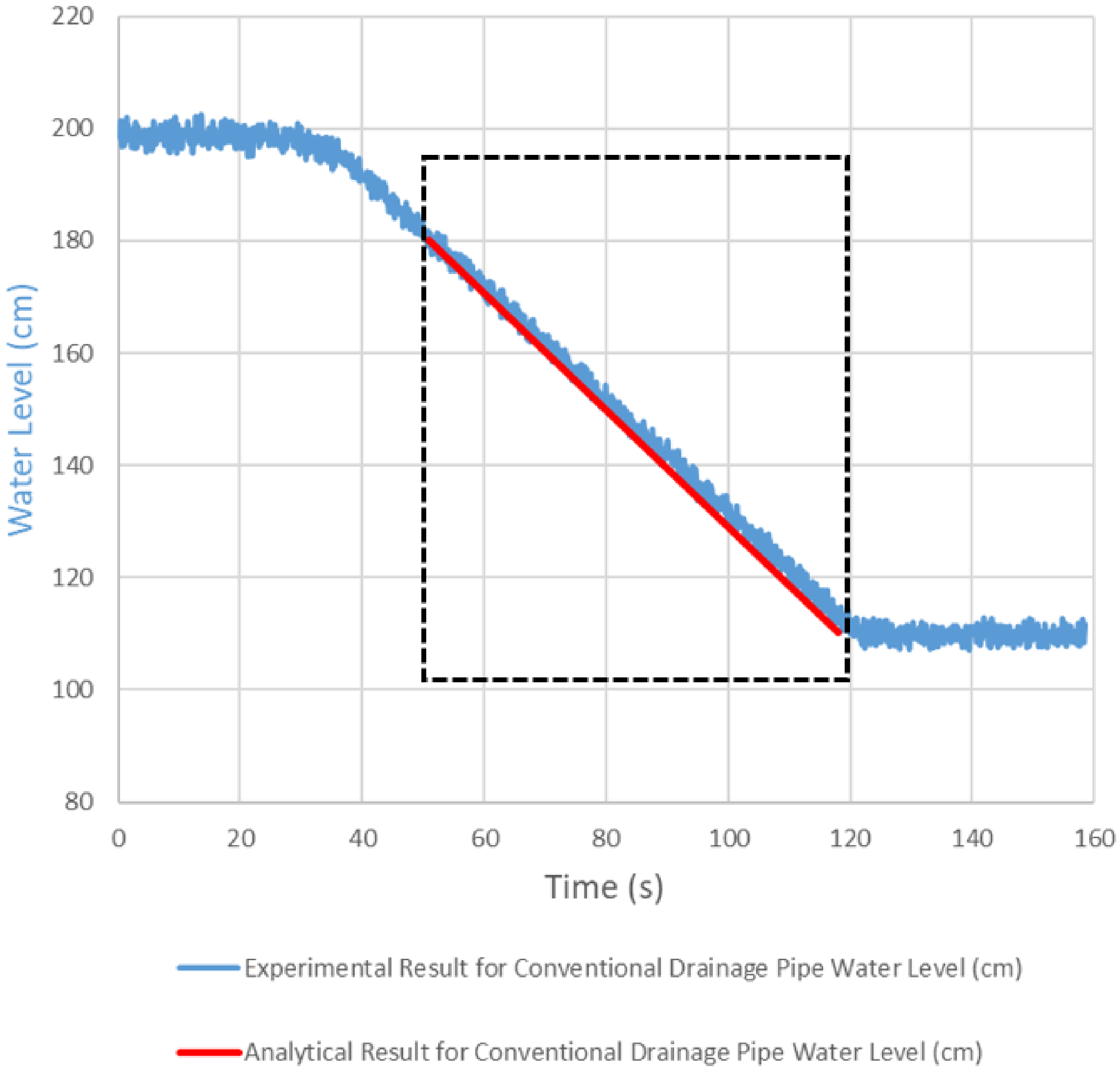

Figure 24: Comparison of the Experimental and Analytical Result (Eq. 18) for the Conventional Drainage Pipe System

Fig. 25 is an analytical comparison of the drainage time between the 6-inch diameter siphon system and conventional drainage pipe system. 140, 160, and 180 cm initial water levels are used to perform the hydraulic performance. The analytical result shows a comparison of the drainage time between 6” diameter of the siphon and conventional drainage pipe system. Fig. 25 illustrates that the conventional drainage pipe system drains the same amount of water faster than the siphon system.

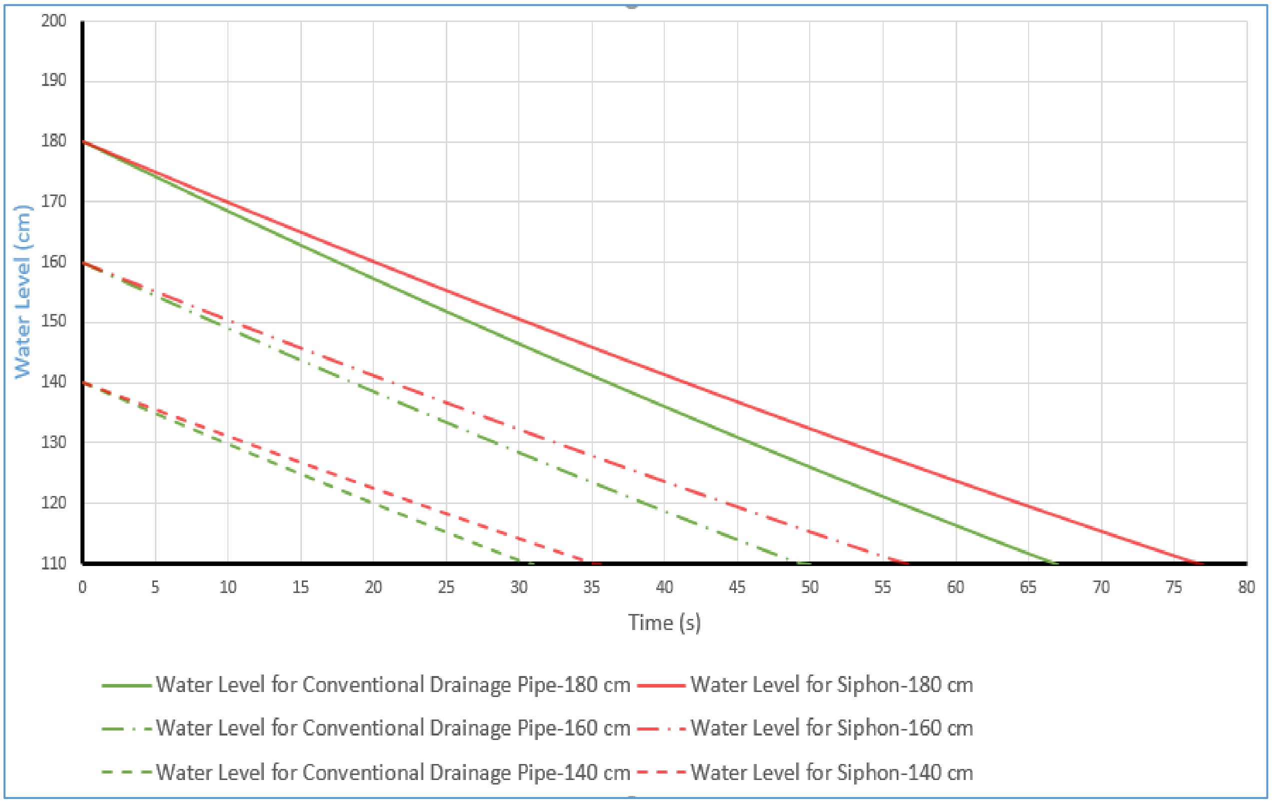

Figure 25: Water Level vs. Drainage Time for 6-inch Diameter Siphon System and Conventional Drainage Pipe System

Fig. 25, calculated from the analytical result, shows the comparison of the drainage time between 6” diameter of the siphon and conventional drainage pipe system. As shown in the result, the water began to release when the water depth was 180 cm at 0 seconds. However, the siphon used a longer time (close to 75 seconds) to release, which is the 3.69m^3 water volume from the water tank than the conventional drainage pipe used (about 65 seconds). The reason caused this phenomenon is that the siphon has higher local head loss friction than the conventional drainage pipe.

In order to release water outside from the water tank more efficiently, several siphons and conventional drainage pipe systems are recommended to use. The following analytic calculation demonstrates the impact of the number of the siphon and the conventional drainage pipe on the drainage time. Fig. 26 and Fig. 27 depict the water depth as a function of time for the number of siphons and conventional pipes.

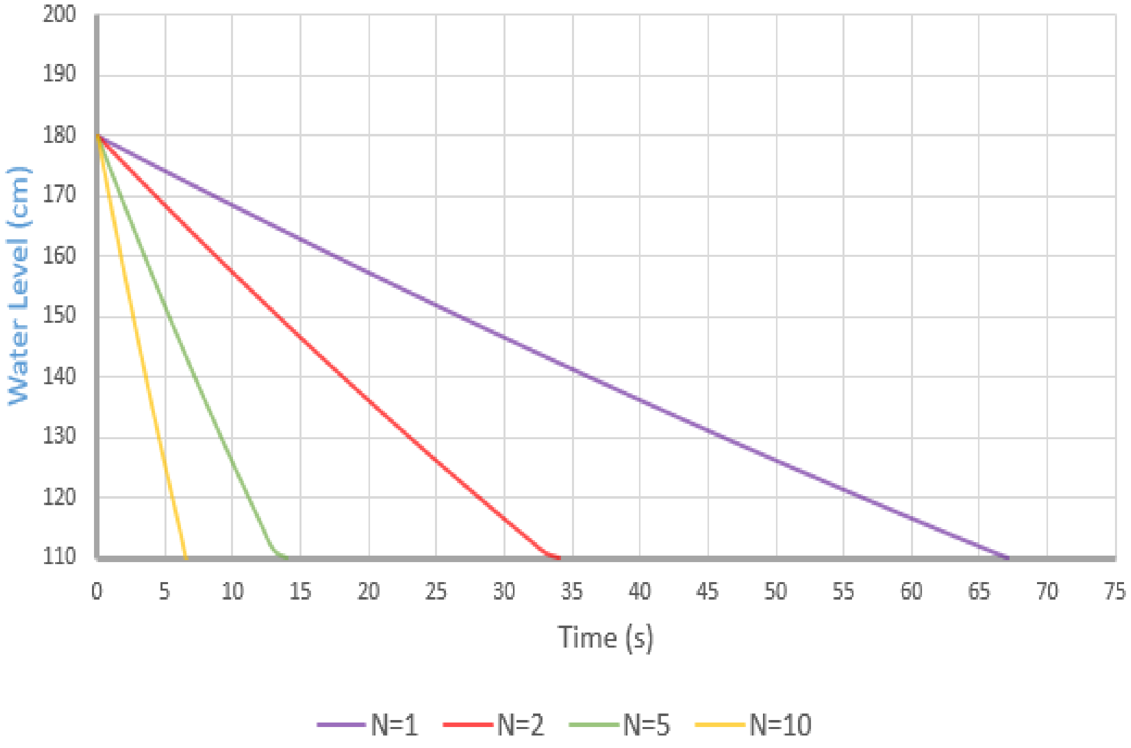

Figure 26: Water Depth as a Function of Time for the Number of 6-inch Conventional Drainage Pipe Systems

According to the results shown in Fig. 26 and Fig. 27, with the number increase of the conventional pipe or siphon used to drain the water, the drainage time decreases significantly. However, it should be noted that when the number of the siphons and the conventional drainage pipes is the same, the siphon still needs more time to drain the water than the conventional drainage pipe.

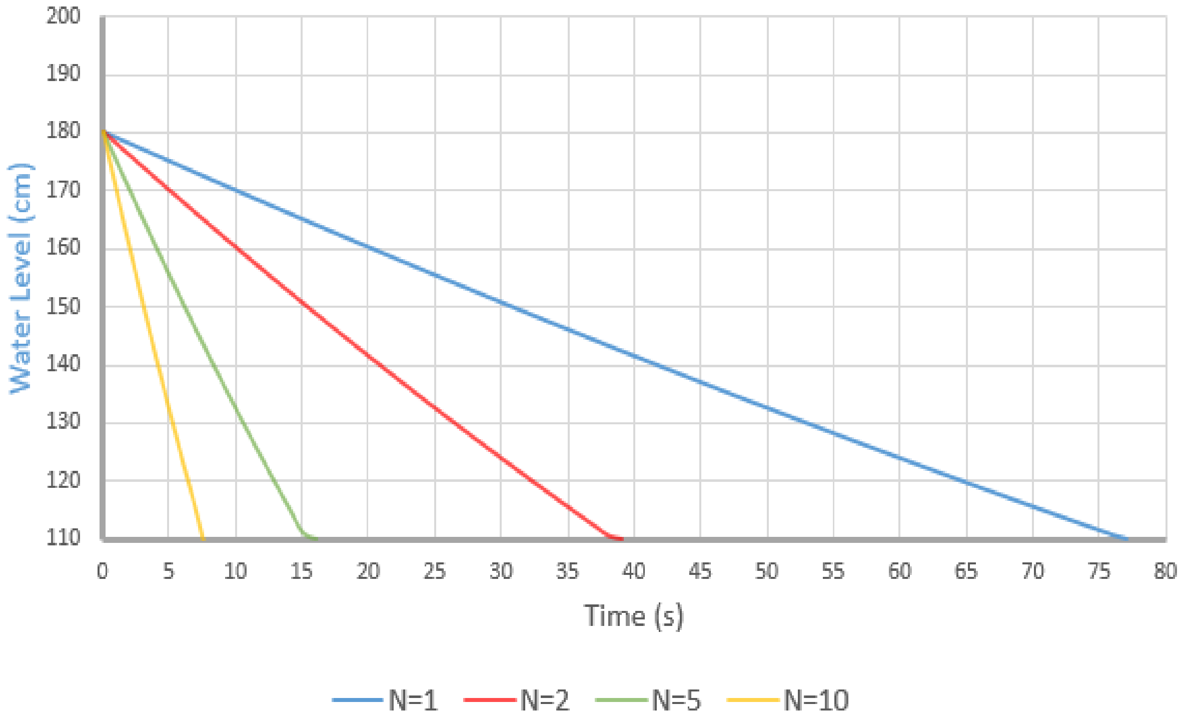

Figure 27: Water Depth as a Function of Time for the Number of 6-inch Siphon Systems

Based on the above analyses in Fig. 26 and Fig. 27, it can be concluded that the conventional pipe is more efficient to be applied for water release than the siphon. Furthermore, the conventional pipe system is slightly more effective than the siphon system for releasing water based on the result given in Fig. 25.

4.4 Comparative Cost Analysis of the Proposed Systems with the Existing Systems

Table 5 and Table 6 illustrate the cost analysis of the proposed siphon system and conventional drainage pipe system, respectively.

Table 5: Cost Analysis of 6-inch Diameter Siphon System

	Unit($)	Quantity	Cost($)
Components of Siphon			
Liquid Level Switch	14.68	4	58.72
Bilge Pump	42.95	1	42.95
Air vent with Solenoid	23.99	1	23.99
6” PVC Swing Check Valve	110.4	1	110.4
6” Actuated Ball Valve	1400	1	1400
6” Solid PVC Schedule 40 Pipe(5 ft.)	39.84	2	79.68
6” Clear PVC Schedule 40 Pipe (1 ft.)	40.216	1	40.216
6” Schedule 40 PVC 90 Elbow Socket	23.69	3	71.07
Schedule 40 PVC Tea Socket	36.45	1	36.45
PVC Drain Cap	35.39	1	35.39
Schedule 40 PVC Coupling Socket	10.82	1	10.82
Schedule 80 PVC Van Stone Flange Spigot	22.66	1	22.66
Connection of Siphon			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
SDR	480	1	480
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**3109.826**

The first column of Table 5 has different components that have been used to construct our siphon system. Liquid level switches are installed in the storage units like wetlands, detention ponds, reservoirs. Basically, these level switches tell us where the water level is when a flooding scenario happens, and then the system responds automatically. To transfer the water in the siphon system from one end to another, the siphon should be primed by priming means that water should be there in the siphon system. To prime the siphon system automatically, a bilge pump and solenoid air valve are used. Both of them are working at the same time. Because the system is smart when the water is not available in the siphon system, the air vent and bilge pump start automatically, and then the siphon is filled with water. Once the system is primed, automatically, those two components stop, and then it is ready to receive orders to transfer the water. Water is transferred when the actuated ball valve is open. A check valve is installed to prevent the backflow of the siphon system from the storage units. Several pipes, elbows, and sockets have been used to construct the siphon system, as previously discussed in Chapter 3. These were the components of the siphon system, as mentioned in Table 5.

Table 6: Cost Analysis of 6-inch Diameter Conventional Drainage Pipe System

	Unit($)	Quantity	Cost($)
Components of Conventional Pipe			
Liquid Level Switch	14.68	2	29.36
6” Actuated Ball Valve	1400	1	1400
6” Solid PVC Schedule 40 Pipe(5 ft.)	39.84	2	79.68
6” Schedule 40 PVC Coupling Socket	23.69	1	23.69
6” Schedule 80 PVC Van Stone Flange Spigot	22.66	1	22.66
Connection of Conventional Pipe			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**2252.87**

Table 6 has different components that have been used to construct the siphon system. Liquid level switches are installed in the storage units like wetlands, detention ponds, reservoirs. Basically, these level switches tell us where the water level is when a flooding scenario happens, and then the system responds automatically. Water is transferred when the actuated ball valve is open. A check valve is installed to prevent the backflow of the conventional outlet pipe system from the storage units. PVC Schedule 40 pipe have been used to construct the conventional drainage pipe system, as previously discussed in Chapter 3. These were the components of the conventional drainage pipe system, as mentioned in Table 6.

The conventional drainage pipe system is easy to install and maintain in the real field. The reason is that only two liquid level sensors are employed in the storage unit. Also, as no liquid level sensors are installed in the conventional drainage pipe system, there will be no air leakage problem.

Different scenarios of cost analysis for the siphon system and conventional drainage pipe system have been performed, and the result is provided in Table 7,8, 9, and 10, respectively.

Table 7: Cost Analysis of 4-inch Siphon System

	Unit($)	Quantity	Cost($)
Components of Siphon			
Liquid Level Switch	14.68	4	58.72
Bilge Pump	42.95	1	42.95
Air vent with Solenoid	23.99	1	23.99
PVC Swing Check Valve	98.48	1	98.48
Actuated Ball Valve	908	1	908
Solid PVC Schedule 40 Pipe(5 ft.)	32.43	2	64.86
Clear PVC Schedule 40 Pipe (1 ft.)	34.67	1	34.67
Schedule 40 PVC 90 Elbow Socket	8.1	3	24.3
Schedule 40 PVC Tea Socket	12	1	12
PVC Drain Cap	5.1	1	5.1
Schedule 40 PVC Coupling Socket	3.7	1	3.7
Schedule 80 PVC Van Stone Flange Spigot	15.61	1	15.61
Connection of Siphon			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
SDR	480	1	480
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**2469.86**

Table 8: Cost Analysis of 4-inch Conventional Drainage Pipe System

	Unit($)	Quantity	Cost($)
Components of Conventional Drainage Pipe			
Liquid Level Switch	14.68	2	29.36
Actuated Ball Valve	908	1	908
Solid PVC Schedule 40 Pipe(5 ft.)	32.43	2	64.86
Schedule 40 PVC Coupling Socket	3.7	1	3.7
Schedule 80 PVC Van Stone Flange Spigot	15.61	1	15.61
Connection of Conventional Drainage Pipe			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**1719.01**

Table 9: Cost Analysis of 8-inch Siphon System

	Unit($)	Quantity	Cost($)
Components of Siphon			
Liquid Level Switch	14.68	4	58.72
Bilge Pump	42.95	1	42.95
Air vent with Solenoid	23.99	1	23.99
PVC Swing Check Valve	224.1	1	224.1
Actuated Ball Valve	1748	1	1748
Solid PVC Schedule 40 Pipe(5 ft.)	94.36	2	188.72
Clear PVC Schedule 40 Pipe (1 ft.)	179	1	179
Schedule 40 PVC 90 Elbow Socket	66.4	3	199.2
Schedule 40 PVC Tea Socket	93.64	1	93.64
PVC Drain Cap	75.63	1	75.63
Schedule 40 PVC Coupling Socket	22.06	1	22.06
Schedule 80 PVC Van Stone Flange Spigot	47.54	1	47.54
Connection of Siphon			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
SDR	480	1	480
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**4081.03**

Table 10: Cost Analysis of 8-inch Conventional Drainage Pipe System

	Unit($)	Quantity	Cost($)
Components of Conventional Drainage Pipe			
Liquid Level Switch	14.68	4	58.72
Actuated Ball Valve	1748	1	1748
Solid PVC Schedule 40 Pipe(5 ft.)	94.36	2	188.72
Schedule 40 PVC Coupling Socket	22.06	1	22.06
Schedule 80 PVC Van Stone Flange Spigot	47.54	1	47.54
Connection of Conventional Drainage Pipe			
P1-540	180	1	180
P1-15CDD2	61	1	61
P1-08TRS	46.5	1	46.5
Solar Panel	119.99	1	119.99
Rechargeable Battery	289.99	1	289.99
TOTAL			**2762.52**

The total cost analysis for all the scenarios of the siphon system and conventional drainage pipe system is shown in Table 11. The siphon system ranges from $2,500 to $4,100, and the conventional drainage pipe system ranges from $1,700 to $2,800. Depending upon the user's requirement, different diameters of the siphon system and/or the conventional drainage pipe system can be used. The smaller diameter will have less discharge than a larger diameter, and it will also cost less money.

Table 11: Total Cost of Siphon and Conventional Drainage Pipe System under Different Diameters

	Total Cost of the System($)	
	Conventional Drainage Pipe	**Siphon**
4" Pipe	1719.01	2469.86
6" Pipe	2252.87	3109.83
8" Pipe	2777.5	4081.03

Table 12 shows the quotations from two suppliers for the 6” conventional drainage pipe system. Due to the confidentiality of the suppliers, the company names are hidden. Supplier 1 and Supplier 2 provide the SCADA panel and total on-site services. Table 11 depicts the total pricing of hardware employed in the field and the control systems provided from two suppliers.

Table 12: 2021 Prices of Two Quotations of SCADA System for the 6-inch Conventional Drainage Pipe

	SUPPLIER 1	**SUPPLIER 2**
Control Panel and On-site Service ($)	33,230	16,560
Scada Software		
Controller Software		
Office Control System		
Hardware ($)	2,252	2,252
Liquid Level Switch		
Actuated Ball Valve		
Solid PVC Schedule 40 Pipe(5 ft.)		
Schedule 40 PVC Coupling Socket		
Schedule 80 PVC Van Stone Flange Spigot		
P1-540		
P1-15CDD2		
P1-08TRS		
Solar Panel		
Rechargeable Battery		
Total	**35,482**	**18,812**

The prices are relatively higher than the proposed system. This thesis minimizes the cost and makes the system more cost-efficient, for instance, for a 6" diameter pipe, the total cost of the remotely–operated siphon and conventional drainage pipe system is $3100 and $2250, while the 6” diameter of SCADA system would cost about more than $18,000 with $2021 pricing.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis presents an integrated hardware and software architecture for gravity-driven and remotely-operated water release from storage units like reservoirs and wetlands along with detention ponds. The proposed architecture is intended for general water release such as flood mitigation, wetland storage management for ecological benefits, among others. This study performed a cost analysis of the proposed system and compared it against the SCADA system. This study also derived an analytical equation for calculating the time-varying flow releases for both types of drainage and validated the equations using the experimental flow release tests. The key conclusions are summarized below:

1) The proposed system for both drainages is significantly less expensive compared to the SCADA system.
2) A conventional drainage pipe can provide slightly better flow performance than a siphon system.
3) The cost of the conventional pipe is relatively cheaper than the cost of the siphon pipe. However, the implementation of the conventional pipe requires earthwork (cut and fill) that would make this system much more expensive. The siphon installation requires a simple anchoring.
4) The derived analytical equations can predict with good accuracy the time-varying flow releases for both types of drainage.

5.2 Recommendations

The following recommendations are made for the integrated hardware and software architecture for gravity-driven and remotely-operated water release from storage units like wetlands, detention ponds and reservoirs. The key recommendations are given below;

1) Internet of Things (IoT) technologies could be integrated in the proposed system to lower the costs even more for the siphon system and conventional drainage pipe system.

2) The drainage experiments should be expanded to a wider range of diameters such as 4, 8, 12 inches for the siphon system and the conventional drainage pipe system.

3) Future release tests should be performed using water with sediment to assess potential clogging issues of the proposed system. In particular, it is recommended to use sediment concentrations similar to those measured in wetlands or detention ponds during rainy seasons.

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APPENDIX

APPENDIX A

Field Setup

FIGURE PAGE

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Figure A-2: Actuated Butterfly Valve …………………………...……………………...60

Figure A-3: NiDAQ Data Acquisition System ……………………………………….61

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Figure A-1: Actuated Ball Valve

Figure A-2: Actuated Butterfly Valve

Figure A-3: NiDAQ Data Acquisition System

Figure A-4: Omega Flowmeter

Figure A-5: Flowline Ultrasonic Water Level Sensor

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