Research Proposal

Quantify the Reliability of the Remotely Controlled Siphon System for Dynamic Water Storage Management Based on ExtendSim platform

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Abstract

After summarizing the previous work, the new questions are identified in this research proposal. The main goal is to focus on quantifying the reliably of the remotely controlled siphon system and the influence of the operation failure of one or more than one siphon on the multi-wetland dynamic management. After preliminary analyzing the problems, ExtendSim platform is highly recommended to solve these problem. Other benefits from this research such as visualization and optimization are also demonstrated in this research proposal.

Keywords: Reliability, Remotely Controlled Siphon, ExtendSim, Optimization

I. Introduction

Comparing with other sever weather events, inland flooding remains one of the greatest threats to the safety of human population in the United State[2]. It is also widely noticed that flood losses are exacerbated by increasing the development of commercial, and tourism area, particularly in the coastal margin. Such urbanization which is normally paved by greater amount of impervious surface to change surface run-off and the concentrate time, and accelerating runoff flow velocity and enlarging peak flow. Consequently, communities, households, and private property are becoming more vulnerable to dam-

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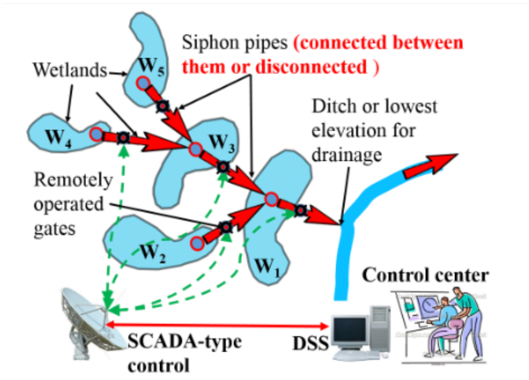
age from repetitive floods. From 1959 to 2005, 4586 reported fatalities caused by floods occurred across the contiguous United States, and the damage was around $ 6.9 billion per year during the period of 1976 and 2006[1, 7, 8]. For instant, one of the most severe events happening recently in Texas would be Hurricane Harvey which caused at least 107 confirmed deaths and total economic losses of $125 billion[6, 9]. Moreover, due to the global warming issue, it has higher possibility to change the pattern of precipitation, which potentially makes the storms, floods and droughts more severe. The traditional approach can reduce inundation of floodplains in several ways. For example, reservoirs reduce downstream peak flow rates, levee and flood walls confine the flow of the rivers, and floodways can divert excess flow. Although structural measures can be effective in reducing floods, they have a limited capacity to mitigate floods since only small parts of the watersheds (river and floodplains) are used for flood management. However, floods as naturally occurring events are dependent not only on rainfall amounts and rates, but also on the topography of the area, land use of the region, soil type of the watershed, and antecedent moisture conditions[5]. Therefore, the potential role of naturally occurring and artificial wetlands in mitigating flood duration and intensity have been widely discussed.

There are few previous studies acclaim that the basins with as little 5% lake and wetland area might lead to 40-60% lower flood peaks. A report from the Environmental Protection Agency[4] concluded that watershed approaches are the most effective approaches to address water resource challenges. This approach can help to maintain and mimic the natural hydrologic system[3] . It can be concluded that wetlands not only provide the ecological infrastructure for watershed systems, but are also believe to provide natural flood mitigation.

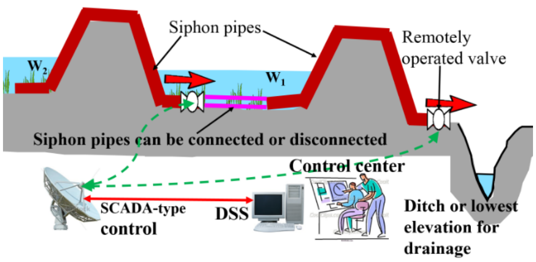
II. Research Proposal

A report of the United Nations[10] concluded that upland wetlands could be effective for small floods, but for large floods, such effectiveness may be significantly reduced because of the excess of their storage capacity. In fact, during rainy season, mild to heavy rainfall events may occur continuously for days or weeks. In these situations, the effectiveness of water storage area is constrained when a heavy rainfall that potentially causes flooding since they may be full of water. Based on this point, Arturo Leon propose a strategy for increasing the effectiveness of storage systems for flood mitigation which could be to release part of the water ahead of (e.g., a few hours or a couple of days before) a heavy rainfall that is forecasted to produce flooding. To make this approach possible, a siphon system is built which can be remotely operated, which is shown as figure 1 below.

Each siphon is consisted of several components, and these components can be generally classified into three groups, which are structure (check valve), sensors (level switch), and actuators, such as pump, air vent, and ac-



(a) *Multi-wetland system.*



(b) *Siphon Arrangement*

Figure 1: *The sketch of remotely controlled siphon system for dynamic wetland management*

tuated valve (See Figure 2). The sensors and actuators are integrated by Programmable Logic Controller, short for PLC, and powered by 24V DC battery and solar panel.

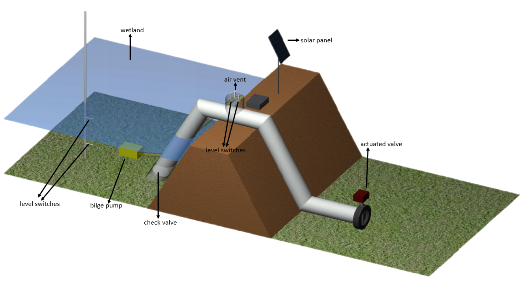


Figure 2: *The sketch of the component of a siphon*

Water level switch can provide the information of water level in the wetland and inside of siphon pipe. Such information is used to determine the condition of when the siphon can releasing water from a wetland and whether siphon flow can be formed inside of pipe. Pump will pump water from the wetland into siphon pipe and at the same time, the air vent is open for releasing air inside of siphon pipe. The check valve only allow water to flow from the wetland into the inside of siphon pipe. When there is no flow, due to the gravity action of the water body inside of the siphon pipe, the cap inside check valve is pressed so the water can be maintained inside of pipe if the water leakage is ignored. The actuated valve can accept orders to open or close. The computer will send a series of optimized operation order through the wireless network to every PLC in the different wetlands to decide whether a siphon or a several siphons need to open (see Figure 3).

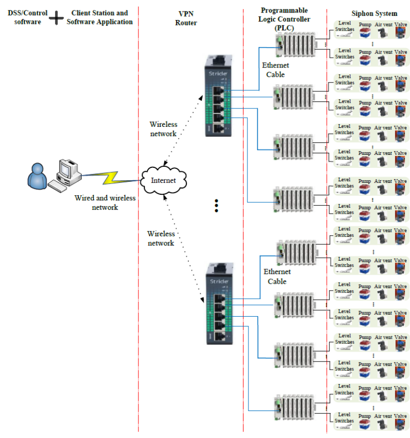


Figure 3: *The framework of wireless connection among the components of a siphon in different wetlands*

These optimized operation order is generated from Decision Support System (DSS) which is the result from the meteorological, hydrological and hydraulic simulation.[1]

Above framework, architecture and technical approach can coordinate multi-wetlands to release water dynamically. However, it should be noticed that although the current industrial simulation software such as HEC-HMS, HEC-RAS, and optimization algorithm can achieve the analysis of flooding inundation, the predication of flow rate, and remote control for such mitigation method, **these approaches can hardly achieve a dynamically intuitively visualization and simulation of multi reservoir system, which would be helpful to provide overall understanding of how water in each wetland changes after taking a decision**. Moreover, the storage capacity of an artificial wetland is mainly determined by the minimum water level to maintain biological activities and the operation storage to alleviate flooding. Facing the fact of the higher price of earth excavation of backfilling for both natural and artificial wetlands, **storage capacity of each wetland should be also an important factor to optimize and be allowed to simulate before doing any earth work**. However, there is no previous work related to this point. Furthermore, **there is no industrial software can simulate siphon process**. Previous work basically use pump in SWMM to represent siphon.

Last and the most important, due to the architecture of the remotely controlled siphon system, every component has uncertainty to fail and are vulnerable to nature environment, which consequently causes operation failure of one or more than one siphon. Such scenario will make wetland loss its flood mitigation ability. In order to improve the reliability, taking the level switch as an example, currently there are two level switches are applied for one water level in case one of them fails, the another one can still provide water level information to the system. It is no doubt that if there are more than one level switch to apply for a same water level, the system will be more reliable, while the price increases as well. Therefore, **there is need to find the optimized assemble architecture to balance between the reliability of the system and the price of the assemble architecture and provide an index to show the reliability for the remotely controlled siphon system for the dynamic water storage management**. However, these is no work to determine the hazard influence of each asset on the dynamic water storage system. Therefore, the research is mainly to answer the questions below,

- What is global dynamic changes among the multi-wetland system? Which wetland can provide maximum mitigation effect during one flooding event, and which one provide minimum mitigation effect?
- What is the reliability of each siphon system in a wetland? What is the worst-case scenario for a wetland to lose its flooding mitigation ability?
- What is the reasonable assembly for a siphon to meet both reliability and econ-

[1] For operation process, video can be referenced by link:
`https://www.youtube.com/watch?v=Uqk0bNkXPAY&t=122s`

omy requirement.

During the research, three objectives below are mainly achieved,

- Provide an approach to dynamic simulate siphon process on ExtendSim platform.
- Build a dynamically intuitively visualized multi-reservoir operation system.
- Identify the hazard impact of each component on the remotely controlled siphon system and provide index about the reliability of the siphon system for dynamic water storage management.

The benefits which could gain in this research are,

1. By building a model to achieve dynamically intuitive visualization of multi wetland system, user could have an overall understanding of how the water storage changes dynamically.

2. Fast identify the hazard impact of each component of the siphon on the multi-reservoir management system in order to provide information to develop emergency measure, at the same time, the resistance ability of siphon architecture can be quantified.

3. According to the vulnerability of each components of the siphon, propose more reasonable architecture assembly.

III. Method

ExtendSim platform[2] consists of a series of functional blocks in the different libraries which are elaborately designed for dynamic system simulation. The platform has been widely using the many industrial fields, such as transportation, system optimization, and chemistry and physics. This platform has strong customized ability to solving challenging problems which other industrial software can hardly solve. Comparing with other simulation platforms, ExtendSim has advantage to creatively deal with the problems and scenarios by developing specific functitonal blocks. Moreover, ExtendSim can simulate thousands of scenarios in a short time. Such advantage is perfectly required by application of assessing reliability of a system or a compenent in the system since the probability characteristics can only be revealed by a plenty of repeated tests. These strengths perfectly meet the requirements to solve the problems in the research proposal.

Due to its strong flexibility and customized ability, the siphon flow can be likely to achieve by the approaches flowing. By applying storage block, and reading the water level data in the database at each time step, water flow rate and water level change and releasing time can be calculated by the

[2] ExtendSim which is developed by Imagine That Inc. is a simulation program for modeling discrete, continuous, agent-based, and discrete rate processes.

Bernoulli equation.

$$Z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + H_{loss} \quad (1)$$

$$H_{loss} = f\frac{l}{D}\frac{v^2}{2g} \quad (2)$$

Taking the water surface in the wetland and outlet of siphon as boundary condition, the P_1 and P_2 will equal to 0. The cross section of siphon pipe is constant which means $V_1 = V_2$. The equation above can be written as

$$Z_1 - Z_2 = 16f\pi^2\frac{l}{D^5}Q^2 \quad (3)$$

In order to analyze the uncertainty and reliability for each component, the method of what-if scenario and the Monte Carlo can be use in the coupling with designed reliability blocks. In the platform, the designed reliability blocks applying Weibull distribution can generate the outage order randomly for each siphon component before simulating the wetland system. After thousands of simulation tests, the reliability of each component for the siphon system can be identified.

During the whole process, the system must meet the requirement of time-step water mass balance and cumulative water mass balance.

$$\sum_{i=1}^{l} WaterInput_i^t = \sum_{i=0}^{m} WaterOutput_i^t + \sum_{i=0}^{n}(Storage_i^t - Storage_i^{t-1}) \quad (4)$$

$$\sum_{t=0}^{T}\sum_{i=1}^{l} WaterInput_i^t = \sum_{t=0}^{T}\sum_{i=0}^{m} WaterOutput_i^t + \sum_{i=0}^{n}(Storage_i^t - Storage_i^{t-1}) \quad (5)$$

Where
l,m,n represent the number of item in the water input, water output and storage area.
t is any time step T is the end time or last time step of a simulation

IV. Time line

The tentative time line is proposed here. According to the work load, the complexity of problem, and working efficiency, the time line could increase or decrease.

1. 24h-40h
   - Build up the first model on ExtendSim platform tO simulate the siphon process.
2. 40h-80h
   - Configure a siphon system which included the operation of sensor and actuator and test the performance of the siphon
3. 80h-120h
   - Configure multi wetland system on ExtendSim platform and achieve water balance in the whole wetland system.
4. 60h-80h

- Applying designed reliability block and analyze the hazard impact on the siphon system and multi wetland system.

5. 40h-48h

- According to the result, provide operation strategy, optimized approach of assembly architecture, compare the robust ability before and after optimized approach.

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