A quantitative analysis and application on overflow prevention in a fish farm area

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Abstract

Flooding is an inevitable disaster in Taiwan, which lies within the most active tropical cyclone formation area in the Western Pacific. Over the past decade, Anna district located near the southwest coast had suffered greatly from inundations. According to Tsai, the two main causes for this disaster are poor drainage system and additional water ditched from local fish ponds[1]. With lots of fish farms located in the research area, this study aims to discover the possibility of inundation prevention integrated with the aquaculture industry.

To understand the drainage characteristics in the wetland area and propose measures of overflow prevention, the drainage system of the Chianan Irrigation Channel was selected as a study area. For the main research method, the Storm Water Management Model (SWMM), was applied to the quantitative simulation of water level. In the simulation, the rainfall data during Typhoon Morakot are applied to examine the capacity of the following scenario with different solutions, which are: 1) current situation; 2) heightening of existing embankments and 3) pre-drainage operation on fish ponds. Based on the result, local governments in Anna district could prevent economic loss and community displacement by pre-drainage operation with the assistance of the aquaculture industry.

Keywords: *Fish farm, Flooding, Pre-drainage, Storm water management model, Anna district*

Research Methodology:
This research makes use of literature study, field survey of the local aquaculture industry, flooding simulation model by SWMM (Storm Water Management Model), and research by design in the further stage. The inquiry took place during research stays in Taiwan.

Key Publications:

1. Hao Chun Lo, "The Metamorphosis of Fishery: The socio-ecological Transformation at Tai-jiang, Tainan." (Master's thesis, National Taiwan University, 2017)

2. Tang Hsiu Kuo, "A quantitative analysis on economic benefits of pre-drainage operation of fish ponds before heavy rainfalls." (Master's thesis, National Cheng Kung University, 2016)

[1] Tsai Chia Tien, "A flood simulation considering lowland areas as detention basins when heavy rainfall in urban cities." (Master's thesis, National Pingtung University of Science and Technology, 2003)

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Introduction

1.1. Problem Statement

Flooding is an inevitable disaster in Taiwan because Taiwan lies within the most active tropical cyclone formation area in the Western Pacific. With an average of four to five typhoons pers year approaching Taiwan, its summer and autumn seasons are always recorded with intensity rainfalls. For example, Typhoon Morakot, which struck Taiwan from August 7th to August 9th of 2009, caused a record-breaking rainfall of 3050 mm within the 3 days. The exceedingly heavy rainfall from Typhoon Morakot generated nationwide floods and debris flows, which resulted in the loss of 682 human lives and approximately NTD $190 billion in total economic loss.[2] To prevent serious damage to downstream wetlands and urban areas, many structural flood mitigation measures such as dikes, floodwalls, and channel improvements have been implemented over the past decades. However, rapid economic growth accompanied by increasing population requires expansion of residential, commercial, and industrial districts. Such man-made changes in land use lead to impervious area increases, vegetative cover removal, and many other topographic variations. Additionally, land subsidence caused by groundwater overdraft for the aquaculture industry further deteriorates the flood-protection functions of existing flood mitigation measures. Rises in potential flooding risk related to such changes thus indicate a need to reevaluate the design criterion for existing flood mitigation measures in flood-prone areas. Hence, quantitative assessment of flooding risk, vulnerability is not only an essential component of water resource management but also a primary concern in the urban design of fish farm areas.

1.2. Thematic Research Question

Besides traditional flood-proofing measures such as building concrete embankments and permanent detention ponds, pre-drainage operations in fish ponds have also been considered an effective way to retain water from rainfall during heavy rainfall events in recent decades.[3] To lower surface runoff, the release of the pressure of drainage systems and increase in the space available to contain floods during typhoons or heavy rainfall events, this study is aimed at quantitatively assessing the effectiveness of pre-drainage operations in fish ponds. Under these circumstances, two following thematic research question will be investigated in the research paper:

(1) How to examine or visualize the effectiveness of pre-drainage operations and using fish ponds as temporary detention basins?

(2) Do these methods cause any negative impact on the physical living environment of farmed fish concerning its species with different essential conditions?

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[2] Lin Po Hsiung, “The Overview of Satellite, Upper-air Sounding andHydrological Observation Pre-and-post Landfallof Typhoon Morakot at Taiwan.” (Master’s thesis, National Taiwan University, 2010)

[3] Hsiang Kuan Chang, “Regional Drainage Characteristics and Overflow Prevention in a Fish Farm Area.” Journal of Taiwan Agricultural Engineering No.59-1 (2013): 15-25

Method

To achieve the objectives and answer the sub-questions, the research method of the thesis includes a field survey of the local aquaculture industry, literature study, and flooding simulation model by SWMM (Storm Water Management Model).

2.1. Literature Review

For literature related to pre-drainage operations in fish farms, there have been several papers that have approved the effectiveness of this application in Taiwan. The fish ponds located on coastal lowland areas are considered to have the capacity of detaining floods.[4] According to Chen Te Hao, the economic loss caused by floods can be minimized by considering fish farms as detention basins applied to control flooding.[5] The results showed that pre-drainage operations in fish ponds can successfully prevent overtopping conditions in drainage channels. By creating more spaces to detain rainfall and control surface runoff, the pre-drainage operation effectively released pressure in the drainage system in the local area.

2.2. Research Area and Field Investigation

To acquire the fundamental data for flood simulation, this study started from a field trip to Tainan in early October. The selected research area is along the Chianan Irrigation Channel, as shown in figure 1. The total length of the channel is about 2.9 km, and the width is between 5 to 18m. The elevation of the bottom of the canal is between -2.1 to -0.6m from downstream to the upper. Due to the unequal siltation, the heights of the embankment on both sides are different, varying between 1.04 to 1.5m. Presented in figure 2, there are a total of 16 sections for research. The total area is 2.42km², with 95 fish farms accounting for 87% of the entire catchment area, and the rest is drainages, roads, and houses. In the study area, the cultured fish species including Milkfish, Tilapia, and Grouper. As figure 3 presents, these different species require different living conditions such as depth of water, salinity, and temperature. These data are also crucial for the pre-drainage operation. For example, with the heavy rainfall, the salinity could be too low after extracting water from the fish pond.

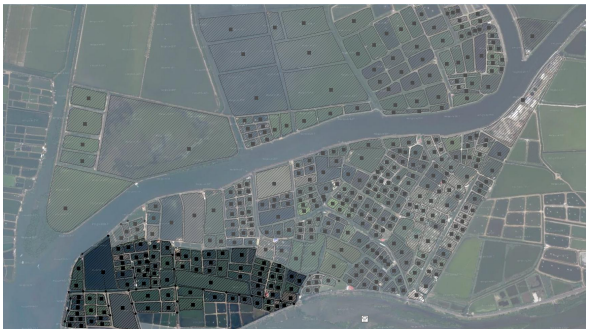

Figure 1. The selected research area in Anna district

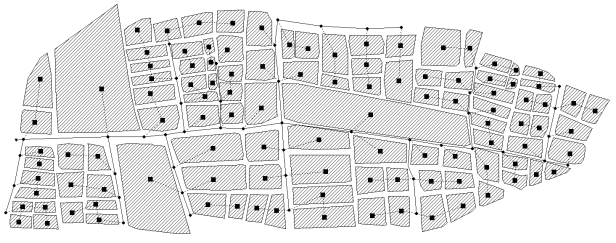

Figure 2. The drainage system in the selected area

[4] Tsai Chia Tien, “A flood simulation considering lowland areas as detention basins when heavy rainfall in urban cities.” (Master’s thesis, National Pingtung University of Science and Technology, 2003)
[5] Chen Te Hao, “A study of the drainage property of fish ponds during heavy rainfall and its impacts on regional drainage systems.” (Master’s thesis, National Taiwan University, 2010)

Figure 3. The essential condition for different species

(Source: Taiwan. Research, Fisheries Agency Council of Agriculture, Executive Yuan. Fisheries statistical yearbook. Taiwan: Chang, Chih Sheng, 2019.)

Species	depth of water	salinity	Temperature
Milkfish	80-100 (cm)	12-30 (ppt)	25-30 (°C)
Tilapia	80-90 (cm)	10-40 (ppt)	10-35 (°C)
Grouper	100-110 (cm)	15-30 (ppt)	22-28 (°C)

2.3. Storm Water Management Model

This study chooses SWMM(Storm Water Management Model) as a simulation model for examining the effectiveness of the pre-drainage operation. SWMM is a dynamic hydrology-hydraulic water management simulation model developed by the Environmental Protection Agency of the United States. Based on the one-dimensional continuous function and theory of dynamic waves, SWMM divides the water flow into surface runoff (RUNOFF) and the main drainage pipe (EXTRAN). The RUNOFF component operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The EXTRAN transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. Before the simulation of the drainage system in fish farm areas, it is necessary to collect the following information:

(1) The total area, depth of the fish farm, and the height of the surrounding embankments.

(2) The location, direction, and elevation of the drainage system, including pipes, channels, storages, pumps, and outputs.

(3) The position and shape of the drainage channel section.

(4) The rainfall data and water level in the selected area and period.

(5) The species of the aquaculture products, and their conditions for survival.

The distribution and total area of the fish ponds can be estimated by aerial photography, collected from the Center for GIS, RCHSS, Academia Sinica.[6] The water storage condition, the connection mode, the direction of drainage flow, and pumping horsepower of each fish pond are surveyed by an on-site investigation. The hydrologic information including unit hydrographs and rainfall data are available on the open sources of the Central Weather Bureau.[7] The distribution and amount of different aquaculture products in Anna district can be obtained from the yearly survey by the Fisheries Agency Council of Agriculture in Taiwan.[8]

[6] Wen, Rong Su. “Center for GIS, RCHSS, Academia Sinica. 中央研究院人社中心地理資訊科學研究專題中心” http://gis.rchss.sinica.edu.tw (accessed November 12, 2020).
[7] Cheng, Ming Tien. “CWB Observation Data Inquire System. 觀測資料查詢 CODiS” https://e-service.cwb.gov.tw/HistoryDataQuery/ (accessed November 5, 2020).
[8] Taiwan. Research, Fisheries Agency Council of Agriculture, Executive Yuan. Fisheries statistical yearbook. Taiwan: Chang, Chih Sheng, 2019.

Results

This research starts with a simulation of the current condition, followed by two improved scenarios. In order to examine the capacity of these solutions for overflow prevention, this study chooses the most extreme rainfall data during Typhoon Morakot, on August 8th of 2009. In this case, the hydrologic information from the rainfall station 467410 in Tainan is applied. The total rainfall in the selected period is 523.5mm, with a peak of 75mm at 5 p.m (figure 4)[9].

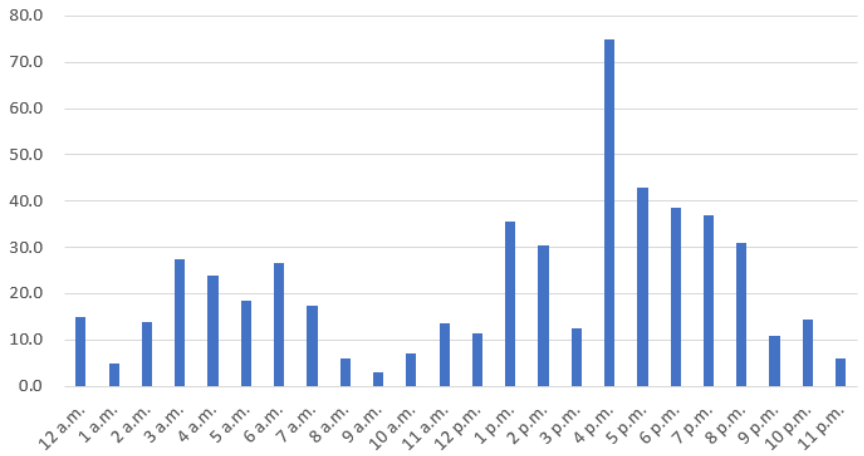

Figure 4. Hourly Precipitation graphs of rainfall station 467410 on August 8th, 2009

3.1. Current Situation

Figure 5 presents the current situation of the relationship between the height of the highest water level, the height of embankments, and the riverbed. The simulation result shows that the highest water level has overlapped with the elevation of the embankment, which indicates that overflow has occurred at section J1, J3, J6, J9, J10, J11, J12, and J14.

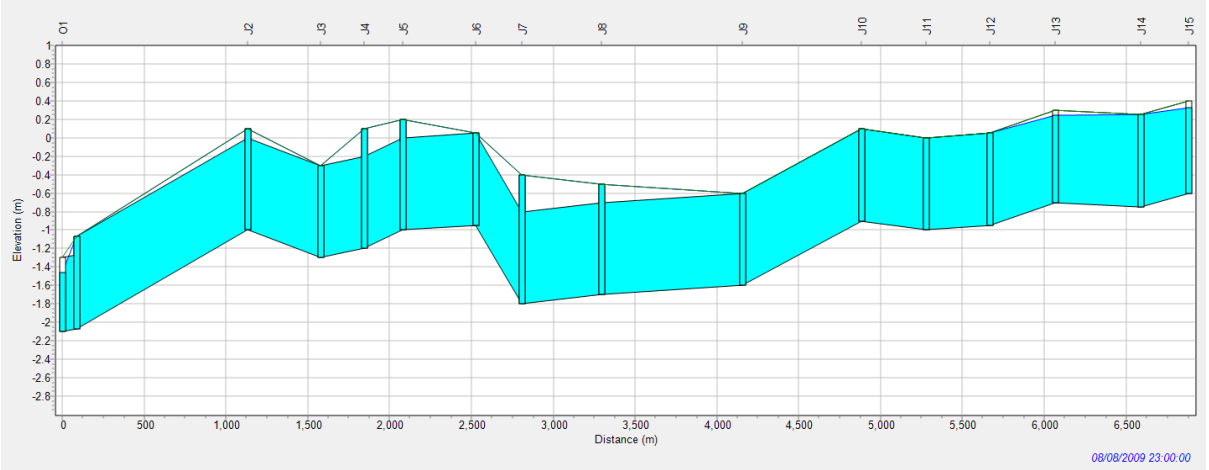

Figure 5. The Water Elevation Profile: Node O1 - J15 (Current Situation)

[9] Cheng, Ming Tien. "CWB Observation Data Inquire System. 觀測資料查詢 CODiS" https://e-service.cwb.gov.tw/HistoryDataQuery/ (accessed November 5, 2020).

3.2. Heightening of Existing Embankments

In order to prevent the economic loss of farmed fish caused by flooding, the local fishermen had heightened the height of dikes by themselves, especially after a serious event like Typhoon Morakot. However, according to the results of on-site investigations, despite the continual heightening of the embankment, flood inundation occurred repeatedly on the site. As figure 6 presented, if it is planned to avoid flooding completely during Typhoon Morakot, the elevation of all dikes must be increased to 0.6m. This lowest embankment height obtained from the simulation result is much higher than the current lowest embankment(-1.1m).

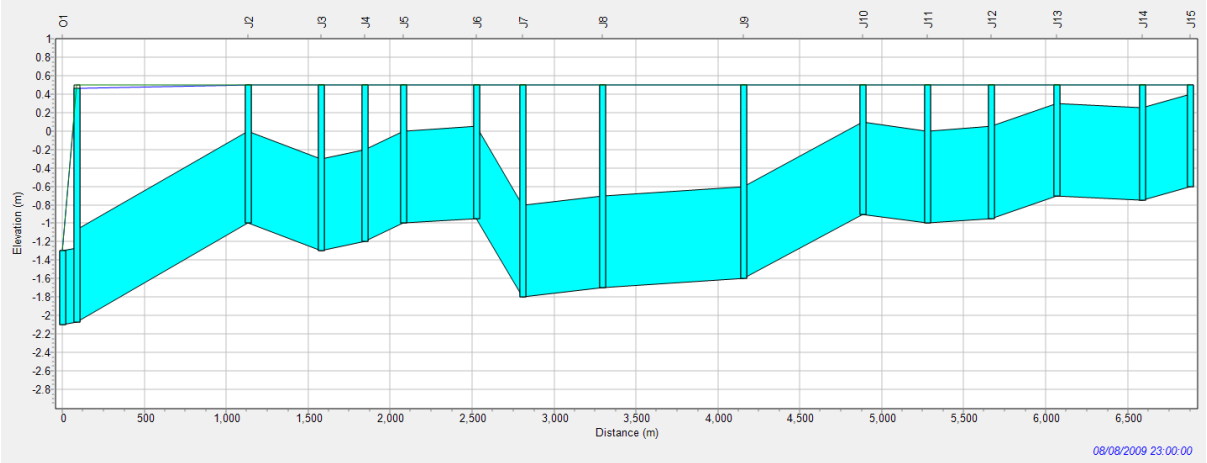

Figure 6. The Water Elevation Profile: Node O1 - J15 (Heightening of Existing Embankments)

3.3. Pre-drainage Operation on Fish Ponds

For the pre-drainage operation, the simulation results show that if the fish ponds are drained off in advance, the water level of the drainage system during Typhoon Morakot can be greatly reduced. After lowering the water level of the fish ponds by 10cm, the highest water levels of the canal can be lowered by 61cm. As figure 7 shows, this scenario will not cause an overflow of the embankment in any section. As a result, the pre-drainage of the fish farm increases the flood storage function and reduces the amount of water drained off from the fish pond to the canal.

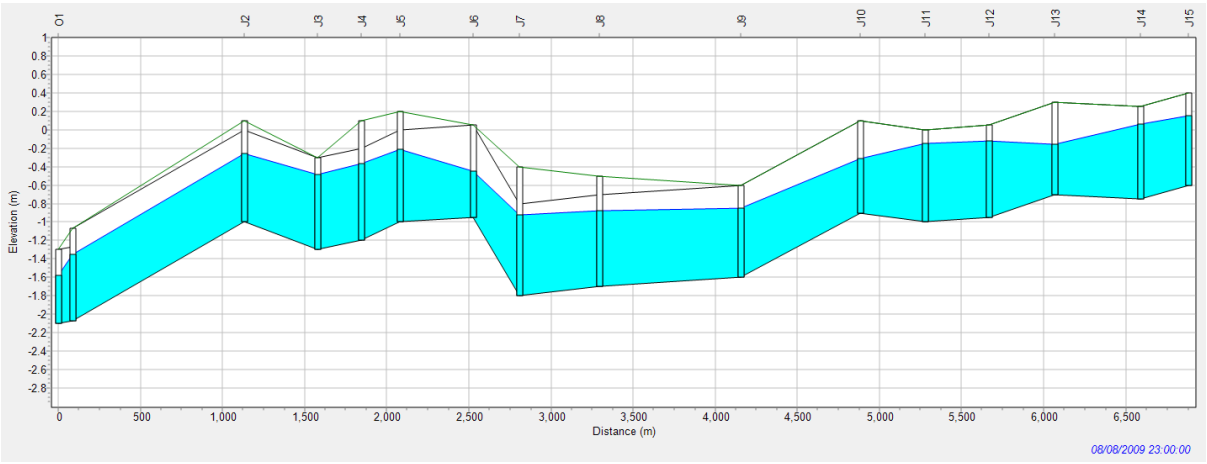

Figure 7. The Water Elevation Profile: Node O1 - J15 (Pre-drainage Operation on Fish Ponds)

Conclusion

In coastal Tainan, aquaculture had become prosperous for more than 200 years, with their products being transported to both domestic and international markets. However, due to the poor drainage system, heavy rainfall and typhoons repeatedly cause serious damage to the local community and the fish farm industry at downstream wetlands. In this study, Chianan Irrigation Channel in Anna district is selected as the research area, and the SWMM numerical model was applied to simulate the water level of the drainage system during Typhoon Morakot. The following is the conclusion of this study:

(1) The effectiveness of pre-drainage operations or other flood prevention can be examined by SWMM simulation. The hydrograph of the targeted drain pipe can visualize and quantize the severity and location of the flood, with the height of the highest water level, the height of embankments and riverbed.

(2) The fish ponds located on coastal lowland areas can be considered as detention basins, which can reduce the pressure of the main drain pipe and extend the response times of emergency.

(3) Compared to heightening the existing embankments, the pre-drainage operation on fish farms is a low-cost and effective solution to prevent overflow and flooding of main drain pipes. The pre-drainage method of the fish pond is to lower the water level before a typhoon. With the outlet gate closed, the detention capacity of the fish farm can be effectively increased.

(4) In accordance with the data of the rainfall forecast, the amount of water needed to be pre-drainages can be calculated according to the results of the SWMM simulation.

(5) The principle of the pre-drainage system is to create space to contain heavy rainfall by lowering the water level of fish ponds. However, because the fish species require their lowest survival depth, the pre-drainage operation has its limitations. According to the on-site investigation of the drainage system and the Fisheries Agency Council of Agriculture, the maximum depth for the pre-drainage system on the site is 10cm.[10]

(6) As stated above, considering different species of farmed fish, the condition of salinity should also be taken into account. With large amounts of water being extracted from the fish pond, the salinity could be too low for certain species after heavy rainfall. In this case, the calculated amount of seawater should be poured into the fish pond before the pre-drainage operation.

(7) For the further design process, the method conducted in this study can be objective criteria to evaluate different proposals of landscape planning and space arrangement on the site. In this way, we can create a manual for creating a fish farm community that works as a system of flood prevention, while achieving a win-win situation for both residential units and the aquaculture industry in the Anna district.

[10] Taiwan. Research, Fisheries Agency Council of Agriculture, Executive Yuan. Fisheries statistical yearbook. Taiwan: Chang, Chih Sheng, 2019.

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