Can We Improve Flood Protection?

Nico Septianus
201380903

Supervised by Dr. Onno Bokhove

Submitted in accordance with the requirements for the
module MATH5872M: Dissertation in Data Science and Analytics
as part of the degree of

Master of Science in Data Science and Analytics

The University of Leeds, School of Mathematics

September 2020

The candidate confirms that the work submitted is his/her own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

Ciliwung River is one of the rivers crossing West Java and capital city Jakarta. This river has play crucial role to fulfil the human needs especially for people that live around it. Pointed as one of the longest rivers, Ciliwung river that runs from Mount Pangrango (Upstream) to Jakarta Bay (Downstream) has actual major flooding issue especially the capital city area which is located near downstream. One of the reasons is due to excessive rain water that came from the upstream. Another reason is lack of public awareness. Many forests around the river were cut to build houses and road access due to growing population over years. Moreover, there are precisely 12 different floodgates to control the River Ciliwung water level scatter between 12 different districts from upstream to downstream. The purpose of this study is to investigate flood that occur in 1st January 2020 by finding the Flood-Excess Volume (FEV) or can be said excess flood water on the designated date. The location that going to be investigated is one of 12 Ciliwung River floodgates that is Depok Floodgate which monitor flood occur in Depok city. Furthermore, multiple hypothetical plans are going to bring out to mitigate the FEV obtained and decide which mitigation plan has the most cost-efficient.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

Annual flooding in Indonesia especially in the capital city Jakarta is inevitable anymore. Since Indonesia is located in equatorial line, therefore it is referred as tropical country which has average annual temperature which ranges from 23-32 degree Celsius (Case *et al.*, 2007). Consequently, Indonesia only experiences summer and rainy season each year. However, there are some concern when the rainy season comes. Many rivers start overflowing which result in flooding across many cities.

Jakarta as a metropolitan area which contain the total population of 9 million people within the area of 660 km^2 has become common spot for annual floods (Forstall *et al.*, 2009). Geographically, Jakarta intersects with 13 different rivers include the largest river, Ciliwung river which has made this city turn into water town during the rains (Brinkman and Hartman, 2008). Ciliwung River, a provincial cross-border river that flows by passing Bogor City, Depok City and ends up in the Jakarta bay is famous for major flooding in the capital city since 20th century (Ratnaningsih *et al.*, 2019). With the total length of $\pm$75km from upstream to downstream and total area cover of 322 km^2. This river had become major water supply system (Fachrul *et al.*, 2007). However, nowadays due to contamination of waste, the function of the river has turned into massive issues such as flooding. As bunch of waste might clog many waterways or flood pipes which originally function to discharge water to other river. Eventually, due to this phenomenon the river level will not going down when the heavy rains come which result in overflowing river water or we usually call it as flood.

This concern has appeared more and more frequently for these past 5 years. This is because many forests nearby the Ciliwung River were replaced by houses. Moreover, the lack of public and government awareness of the environment is another problem as well. For instance, the lack consideration for river normalization which the act of removing waste from the river and postponing mitigation plan project such as building reservoir or flood walls.

The figure below is the map of the River Ciliwung which start from Mount Pangrango (Upstream) and ends up at Jakarta Bay (Downstream).

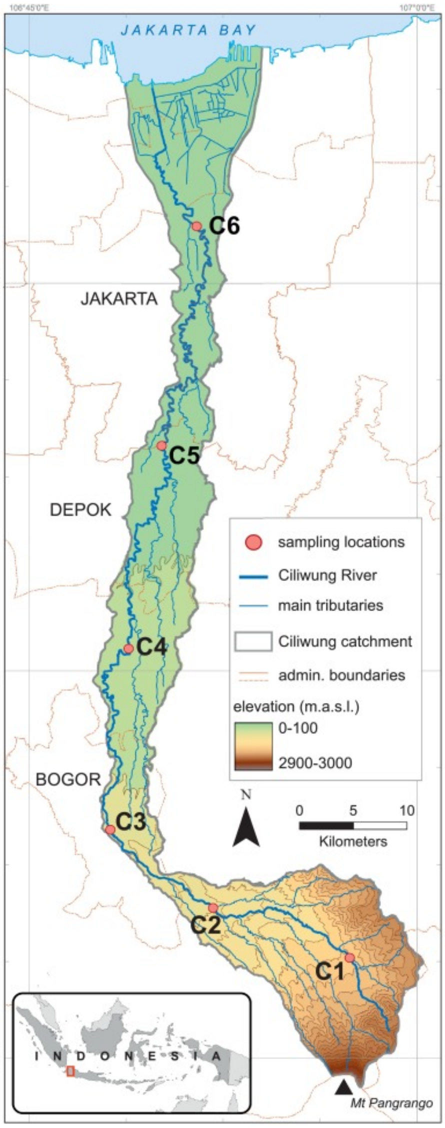

Figure 1.1: Ciliwung River map, the river flows from Mount Pangrango (Upstream-South) can be seen at the bottom side of the figure and end up on Jakarta Bay (Downstream-North) can be seen at the top side of the figure.

1.2 History of River Cilwung Famous Flood

1.2.1 The 2007 greatest flood

The 2007 flood is one of the infamous floods occur in West Java, Banten and Jakarta province. Precisely, it is during rainy season on February 2007, the flood managed to engulf three-quarter of the capital city (Mohsin, 2015). WHO (2007) stated whether there are some reason for unexpected Jakarta flooding in 2007, one reason is due to high sea tides that occurred on northern part of Jakarta which also leads to subsidence in the north. North Jakarta is famous for the last stop of Ciliwung river which end up in the Java sea. However due to high tides and subsidence, the city became vulnerable to flood when the heavy rain comes.

Figure 1.2: The 2007 flood in the north Jakarta due to high sea tides and subsidence (left). The high sea wall that separate the sea and the residence in the north Jakarta (right).

Another reason is, due to lack of preparation from government by neglecting some flood mitigation construction project. For instance, they delayed the construction for East flood canal (Banjir Kanal Timur or BKT) in Jakarta which actually proposed in 2002. As the result, Jakarta only owned West flood canal (Banjir Kanal Barat or BKB) which was built during Dutch colonization era in 1983 to preserve the excess water from the consecutive rainfall in February 2007 which in fact it is not enough (Steinberg, 2007). In addition, shrunk on several floodways due to waste dumping became the concern for 2007 flooding as well. Floodways is the underground tunnel/pipe function as water transfer from one river to another river or reservoir which activated only when the river is no longer could store more rain water. However, the shrunk on floodways caused the water flows with longer duration than usual.

WHO (2007) also added whether the flooding had result in deaths, infrastructure damage and economic lose. From the data, WHO (2007) found total of 69 deaths mostly due to electrocution (late electricity cut out from the electrical company) and drowning from flood. Furthermore, the estimate loss from this event reached US$ 450 Million, mostly from damage taken through infrastructure and private assets.

In response to this catastrophe, the government proposed some mitigation plan post 2007 great flood. The plan consists of rushing on the completion of the East flood canal which is crucial to mitigate flood water in upcoming flooding event. Some action being taken as well such as clearing waste from floodways, raise public awareness about flooding and river normalization. However, it did not last long until 6 years ahead, another big blunder by government has result in another big flood.

1.2.2 The 2013 Jakarta flood

Another similar huge flood occurred at Jakarta in January 2013. This time the East flood canal is built, yet there is one issue about this canal which is it did not connect with Ciliwung river. As described before, the famous Ciliwung river always experiences in overflow when the rainy season came. This blunder resulted the capital city of Indonesia witnessed another huge flood.

Figure 1.3: the East flood canals or Kanal Banjir Timur (KBT).

Moreover, similar issue to the 2007 flood. Nevertheless, in 2013 the 30-m West flood canal collapsed after the continuous rainfall occur (Sedlar, 2016). Apparently, Jakarta cannot rely with West flood canal anymore as some of the canal dike has collapsed due to multiple floods and elements like density, structure and height of the land of Jakarta has changed since the Dutch colonization era. Therefore, government is expected to bring some changes to the capital city after the canal collapsed. Since then, many residences started pressuring the government to come up with certain plan to prevent upcoming flood after the 2013 flood in Jakarta. As the result, they came up with some construction plan for dam. In 2016, they started the project on building 2 big dams, which is Sukamahi dam and Ciawi dam which are located in upstream close to Mount Pangrango. The location is intended so it can connect to the upstream of Ciliwung river which hopefully could mitigate the rainwater that came from upstream (Mardjono *et al.*, 2018). These dams are expected to be finished in the end of year 2020, unfortunately another huge flood and huge loss occurred recently in 1^{st} January 2020 in Jakarta before the dams are finished.

1.3 Aims

In this report, I am going to investigate the flood that occur in Depok floodgate (one of the Ciliwung river floodgate) on early January 2020. Using the height, river-flows and time parameter obtained from the Jakarta-flood statistic website[1]. These data are needed to find the Flood-excess volume (FEV) or the total volume of water that cause the flood and proposed some mitigation plans to mitigate the total FEV obtained. Finally, among all the mitigation scheme find which one has the better cost effectiveness and feasible for future flood event.

[1] Website for Jakarta-flood statistic http://poskobanjirdsda.jakarta.go.id/Pages/grafikDataTinggiMukaAir.aspx

Chapter 2

Methodology

2.1 Flood-Excess Volume (FEV)

2.1.1 Definition

FEV or flood-excess volume is the volume of river discharge (in units m^3) over certain period which cause flooding on specific river location (Bokhove *et al.*, 2019). Simply, FEV can be put as the river water which cause flooding. Therefore, the amount of these volume is wished to reduce to zero using some flood mitigation scheme. By doing so, it is believed the upcoming flood can be prevented.

Initially, to estimate FEV there are some constraints need to be determined. One is h_T or river level threshold when the flood starts occur (flood threshold). This value is important as this will determine when is the starting point level of flood and it controls the FEV. By having higher flood threshold means there will be less flood or lower FEV value (Bokhove *et al.*, 2019). Furthermore, if we increase the h_T to the maximum flood level, the FEV will yield zero.

Since, every river has distinct flood threshold, hence one simple way to obtain the value is via environment agencies or Jakarta-flood statistic website. Another way to obtain h_T is through some media, picture or Gaugemap from monitoring station that show the value. Nevertheless, the result of h_T might distinct for different method which lead to some ambiguity for h_T value. Despite that, as long h_T value is convincing and came from legitimate source, it might be viable to use for further estimation.

2.1.2 Rating Curve

Another constraint needs to introduce before estimate FEV is rating curve. In every river monitoring station, it is very common that they have the record of variable interest for hydrology likewise river level h (m), discharge level Q (m^3/s) and precipitation rate. Since the free-surface height varies little, the measurement of river level can become the mean height $\bar{h}$ (m) over the cross section (Bokhove *et al.*, 2018). The rating curve basically is the relationship between the discharge level Q and river level $\bar{h}$ where,

$$Q = Q(\bar{h}). \tag{2.1}$$

This eventually will form a solid curve line out of multiple scatter plots.

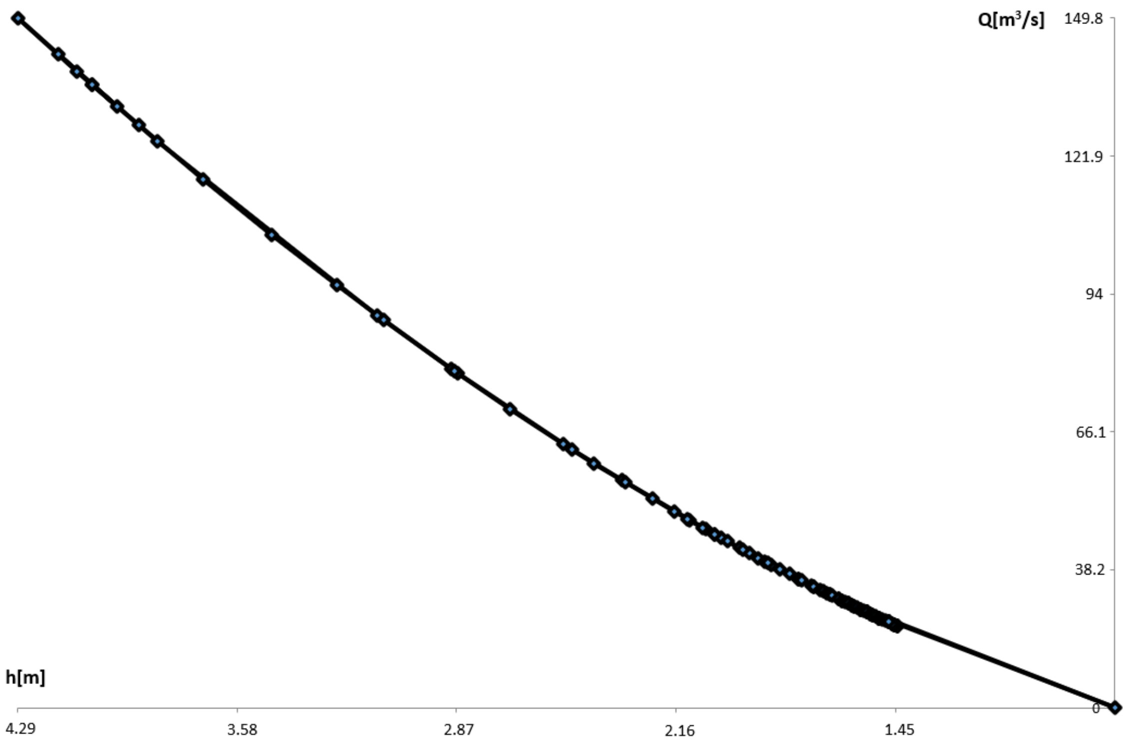

Figure 2.1: Rating Curve which is constructed by relationship of river level $\bar{h}$ with the discharge level $Q(\bar{h})$. The discharge level can be calculated through equation **(2.3)**, using the input of given river level data.

Note that, Q can be represented as a function of time, as the original data of river level $\bar{h}$ is actually in the function of time, so we can write the equation as,

$$Q(\bar{h}) = Q(\bar{h}(t)) = Q(t) \, or \, Q_t. \tag{2.2}$$

In contrast, there are some monitoring stations that are not equipped with such technology to record the discharge level of the river. To overcome this problem, the environment agencies try to fit the curve with the data. The data consist of record from direct measurement involving numerous fitting coefficient for discharge level and original data for river level. From the measurement, it will produce a formula of discharge level with certain dependent parameter include the river level as input. This results in every river as different rating curve parameter and input.

According to Rahmasary (2013) in her paper, the rating curve for Ciliwung river was observed using recession method with assumption of the river baseflow is exist every year and peak of hydrograph in specific time is known. As the result, such rating curve is constructed,

$$Q(\bar{h}) = a(\bar{h} - b)^c. \tag{2.3}$$

The rating curve has typical equation with varying coefficient a, b, c and input parameter river height $\bar{h}$. Here a, b, c is initial discharge, recession constant, ratio to peak respectively. Rahmasary (2013) also added the value a = 11.403, b = 0.2, c = 1.715 respectively for Ciliwung river is provided by the environment agencies upon request. Since, $Q(\bar{h})$ has dimension of [m^3/s], which means the right-hand side of the equation $a(\bar{h}-b)^c$ need to be in same dimension. $\bar{h}$ has dimension of [m], causing b has the dimension of [m] to allow both coefficients subtract each other. c is a power which is dimensionless. To complete the dimension of [m^3/s] for equation $a(\bar{h} - b)^c$. This force a to have dimension of [m^{3-c}/s].

2.1.3 Estimation of FEV

From part **2.1.1**, the chosen h_T (flood threshold) value is going to be converted to value of discharge level via rating curve. Basically, using **(2.3)** we might obtain $Q(h_T)$, and we know that $Q(h_T) = Q_T$ by the property **(2.1)**. After obtaining Q_T, FEV or V_e now can be measured as the integral over discharge over certain flood duration. It can be written in equation as,

$$V_e = \int_A^B (Q - Q_T) dT_f. \tag{2.4}$$

The $Q - Q_T > 0$ which means all discharge level Q chosen need to be above the flood threshold h_T. Since the threshold discharge Q_T associated with the flood threshold h_T. Moreover, the integral is in the time function T_f which is duration flood (in second) happen between A and B (Bokhove *et al.*, 2018). For further detail, this can be seen through **Figure 2.2** which illustrate the hydrograph and the blue region is the total FEV which the value all above flood threshold h_T in the duration T_f.

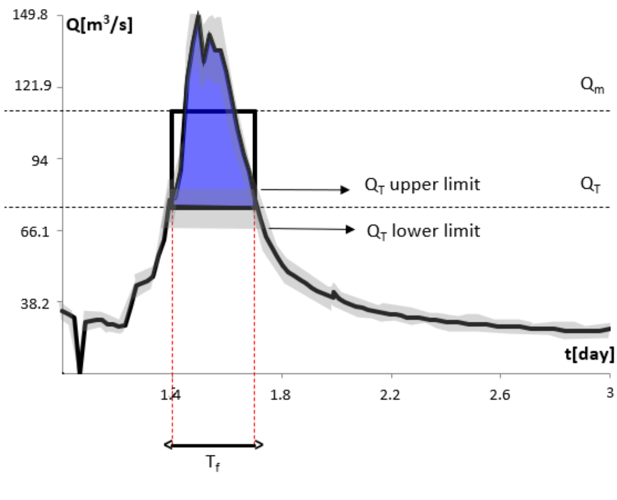

Figure 2.2: The plot for the hydrograph shows the relationship between discharge level $Q(\bar{h})$ and the duration t. (the blue region represents the total FEV over certain flood period T_f).

However, it is impossible to have exactly calculate this integral due to the time increment issue ($\Delta t \to 0$), so some approximation was made for FEV. There are 3 different estimation with vary accuracy.

The first and most accurate approximation V_{e1} requires the knowledge of the river level over certain time period, flood threshold h_T, and the river flow rate or rating curve coefficient. This estimation is based on the original idea, which by finding the total flood volume of water discharge over certain period through summation. The first approximation of FEV, V_{e1} is given by

$$V_{e1} = \sum_{k=1}^{n} (Q(\bar{h}_k) - Q_T)\Delta t. \tag{2.5}$$

Where n is the number of $Q(\bar{h})$ value above the flood discharge threshold, and Δt is the increment between time of $Q(\bar{h}_k)$ and $Q(\bar{h}_{k+1})$. Since, we know T_f is the duration of the flood period. Therefore, it is pretty obvious that $\Delta t = T_f/n$. Furthermore, the approximation of V_{e1} increases as the Δt value decreases, so by setting $n \to \infty$, then $\Delta t \to 0$. This condition which make the equation **(2.4)**, where FEV equals to the exact integral of the curve $Q(\bar{h})$ above Q_T over the duration of flood period T_f. As stated before, this FEV value equals to the blue shaded region in **Figure 2.2**.

The second estimate of FEV, V_{e2} requires the similar knowledge of V_{e1} with one additional component which is the average discharge above the flood threshold denoted by Q_m. Nevertheless, the second approximation V_{e2} is still defined as the product of the flood duration with excess of the mean discharge Q_m over the flood discharge threshold Q_T. The equation is given by

$$V_{e2} = T_f(Q_m - Q_T). \tag{2.6}$$

Where Q_T is the discharge corresponding the threshold height h_T. V_{e2} be represented as the area of the rectangle in **Figure 2.2**. However, this approximation is less accurate since it uses average flow rate to estimate the FEV.

For the third approximation, V_{e3} is the last resort of approximation. With condition unknown rating curve and river height measurement are not automatically taken. V_{e3} still requires the knowledge of river threshold h_T, the maximum discharge level Q_{max} which associates with the maximum river height h_{max}, and the duration of flooding. Using these knowledges, the average river height h_m during the flood period can be obtained by such equation,

$$h_m \approx \frac{h_{max} + h_T}{2}. \tag{2.7}$$

With this result, we can obtain both flowrate Q_m and Q_T through linear interpolation with corresponding h_m and h_T,

$$Q_m \approx \frac{h_m}{h_{max}} Q_{max}. \tag{2.8}$$

$$Q_T \approx \frac{h_T}{h_{max}} Q_{max}. \tag{2.9}$$

By plugging in the equation **(2.8)** and **(2.9)** into **(2.6)**, therefore the new FEV approximation is constructed. The third approximation of FEV, V_{e3} is given by

$$V_{e3} = T_f \frac{Q_{max}}{h_{max}} (h_m - h_T). \tag{2.10}$$

2.2 Mitigation Plan

2.2.1 What is Mitigation Plan?

Later the value of FEV we have obtained are going to be mitigated through proposed and hypothetical scheme. Basically, these schemes are alternative to mitigate the damage come from flood water. Cost efficiency are going to be applied as well to find the most affordable and feasible alternative. This can be undertaken using the calculation of the price per percentage of FEV for each scheme.

2.2.2 Example of Mitigation Plan

Mitigation can be done in the form of natural and structural. Both can come in handy depends on the implementation on the situation. The example of structural mitigation measures such as build dams, floodways, flood walls.

- **Dams** - One of structural mitigation, which solely constructed to minimize flood risk in the downstream. Unlike reservoir dams, the function is not as water reserve but as control of the flow stream. Dams frequently build on the upstream and by minimizing water flow on the connected river on the rainy days, this can prevent the downstream river from overflowing. The slow down flow function can be triggered when water level increases above the spillway in flood and the spillway of the dam is located in the riverbed (Climate Technology Centre & Network, 2017).

- **Flood walls** – This alternative conceived as one of the feasible structural mitigation. By simply building wall or raise higher wall along the river which function similar as a capacity to hold certain water volume.[2]

- **Floodways** – Relatively build underground, the design looks like huge pipe which function to transfer or channel the flood water from one river (usually the vulnerable to flood)

[2] This definition can be found http://thebritishgeographer.weebly.com/floods-and-river-management.html

to another river (which has huge amount of volume capacity) or reservoirs. The amount of waters carried by floodways is typically large amount and in the significantly high velocity than natural floodplain (Green *et al.*, 2007).

Beside the structural mitigation, there is also natural mitigation plan which possibly restore the land from flooding. The example of natural mitigation is tree planting.

- **Tree planting** – Plant tree along the river or empty area near the rivers. Function to absorb the flood water. However, this could be very risky since it is not possible to know how many waters contained in a tree which makes every tree has different absorption rate. Normally, a mature tree estimates to absorb 11,000 gallons of water per season (4-5 months).[3]

However, it is not easy to achieve such mitigation scheme since these schemes require an empty large land to build the structure or plant trees. Therefore, excavate land and relocation could be the solution to have enough space to work on these mitigations. This concern has become never ended argument between the government and the residences who live near the river and are going to be relocated. On the one hand, by prevent upcoming flooding through these schemes will benefit the public welfare in the future. On the other hand, the people unwillingly their home (near the river) to be destroyed forcefully by the opposition as these people are mostly from the low-income family and possibly their incomes might depend on the river as well. By relocating the locals to more decent place to stay, some concern might appear. For instance, the bills and fees in a small apartment are usually higher than they used to live, which technically are not benefitting them.

[3]The tree absorption rate can be found at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5269813.pdf

Chapter 3

Code Verification Analysis

3.1 Software Incentive

All data storage includes analytic and results which will be shown below are processed in Microsoft Excel with Macro code. The incentive of using excel instead of another coding software is excel is must be a well-known software by everyone. It is also accessible. Especially, for the non-tech companies which do not deal with coding software much such as python or R-studio.

Moreover, just using the Excel Macro, many works still can be done in ease. Since the Excel Macro (for generate graph) and Excel worksheet (for store data) are connected, thus the analytic can be done remotely just in excel.

Another benefit, by having the code and results written in Excel, it does not require a person to install many different software and packages to access the code and results, yet just open the excel file the graph and code can be seen directly and it is very understandable.

3.2 Recreation of Quadrant Plot

Before going through the whole analysis of FEV model for the 2020 Ciliwung flood, it is better to test the reliability of the existing code. The existing code is provided by the previous project for FEV analysis on several test river in UK such as Don, Aire and Thames river. Since all previous codes was worked on both python and R-studio. The code cannot be implemented right away into the Excel Macro.

The purpose of this test is to produce similar outcome as the past paper with code implemented on the Excel Macro, this include the three-panel graph and the mitigation box. Another aim is that we would like to achieve by improving the three-panel graph with error bar which going to be implement on the rating curve and the hydrograph section. The test code will count reliable when both aims are fulfilled and it shows similar results to the previous paper.

The verification is going to be performed on 2 different test rivers that already built previously which are Don River for June 2007 flood and Aire River on December 2015 flood.

3.2.1 The 2007 flood on Don River (Sheffield)

It began due to the heavy rain that pouring down the country on June 2007. This had caused severe flooding over the country, includes Sheffield which is believed as the one of the worst causalities. This huge flooding resulted severe damaged to the properties and death (The Yorkshire Post, 2017).

The analysis is going to carry out for the 2007 flood in Sheffield. Through the monitoring station at Hadfields, the investigation on River Don can be performed. Whilst on flood, the river level recorded at peak of 4.675m on 25^{th} June 2007. Below is the recreated three-panel graph for River Don from Hadfields monitoring station with the error bar adapted from the previous author.

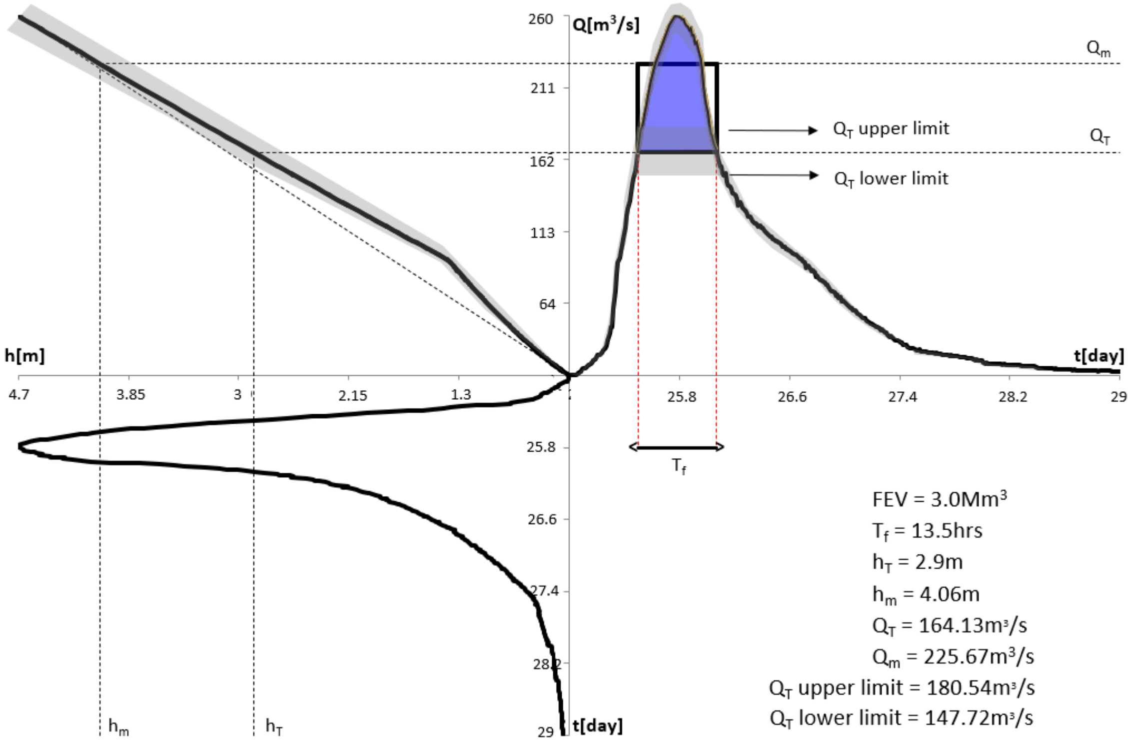

Figure 3.1: The quadrant plot for 2007 flood of the River Don at Hadfields. The rating curve can be seen on the upper left quadrant which calculated using equation **(3.1)** and coefficient from **Table 3.1**. The dash line on the rating curve is the linear approximation. The relationship river level $\bar{h}$ and the discharge level $Q(\bar{h})$ between the flood duration T_f which is 13.5 hours can be seen on the lower left and upper right respectively. Finally, the error rate 0.05 given by the EA is applied on rating curve, hydrograph and Q_T which shows by the shaded grey area.

The rating curve coefficients are provided by Environment Agency, however for the test river it has the certain limit for corresponding coefficient. This means the coefficient used is depends on the specific height which group by certain range between h_{j-1} and h_j. Similar, to the equation **(2.3)** we can write the equation as,

$$Q(\bar{h}) = a_j(\bar{h} - b_j)^{c_j}. \tag{3.1}$$

j	h_{j-1} [m]	h_j [m]	a_j [m^{3-c}/s]	b_j [m]	c_j [-]
1	0	0.52	78.4407	0.223	1.7742
2	0.52	0.931	77.2829	0.3077	1.3803
3	0.931	1.436	29.5956	-0.34	1.2967
4	1.436	3.58	41.3367	-0.5767	1.1066

Table 3.1: The coefficient provided by the Environment Agency, the coefficients a_j, b_j, c_j varies between 4 bounds h_{j-1} and h_j. To decide, it depends on the river level $\bar{h}$ we choose to calculate which required for construct the rating curve.

Finally, by putting the corresponding FEV into an illustration of 2-metre-deep square lake. The recreation of the box can be seen below,

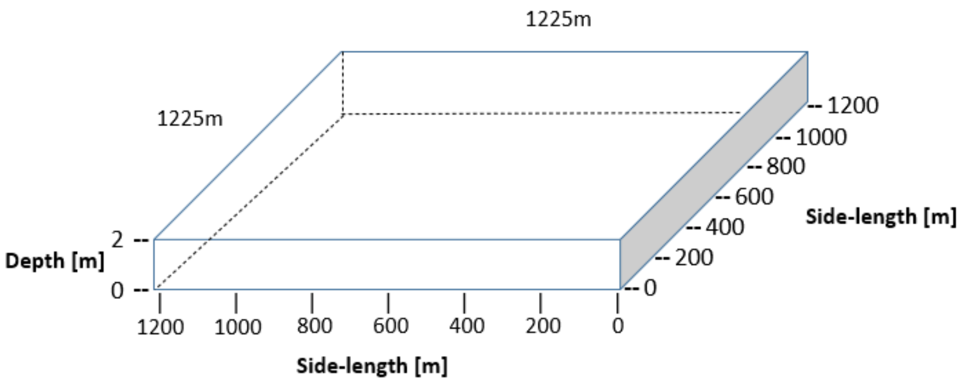

Figure 3.2: 2-metre-deep Square lake for 2007 River Don flood at Hadfields monitoring station. The side length is 1225m each which calculated from $\sqrt{\frac{FEV}{2}}$.

3.2.2 Flood on Aire River (Boxing Day 2015, Leeds)

In Christmas period on 2015, Leeds experienced intense rainfall. This caused the Aire River bank to break and result in flood. Back then in 1866, Leeds also occurred a catastrophic flood which caused several deaths and damage on property. However, the flood peak on 1866 just reached a third of the 2015 flood. Therefore, 2015 flood has attracted many attentions especially on the flood defence sector.[4]

The analysis on the boxing day 2015 flood in Leeds will be performed. The investigation is on the Aire River through Armley monitoring station. The peak of the flood level is 5.21m on December [5]. Below is the recreated three-panel graph for River Aire from Armley monitoring station with the error bar adapted from the previous author.

[4]History of River Aire flood can be found at http://kvp.org.uk/flooding.htm

[5]The peak at 2015 flood at Armley available at https://riverlevels.uk/river-aire-leeds-armley

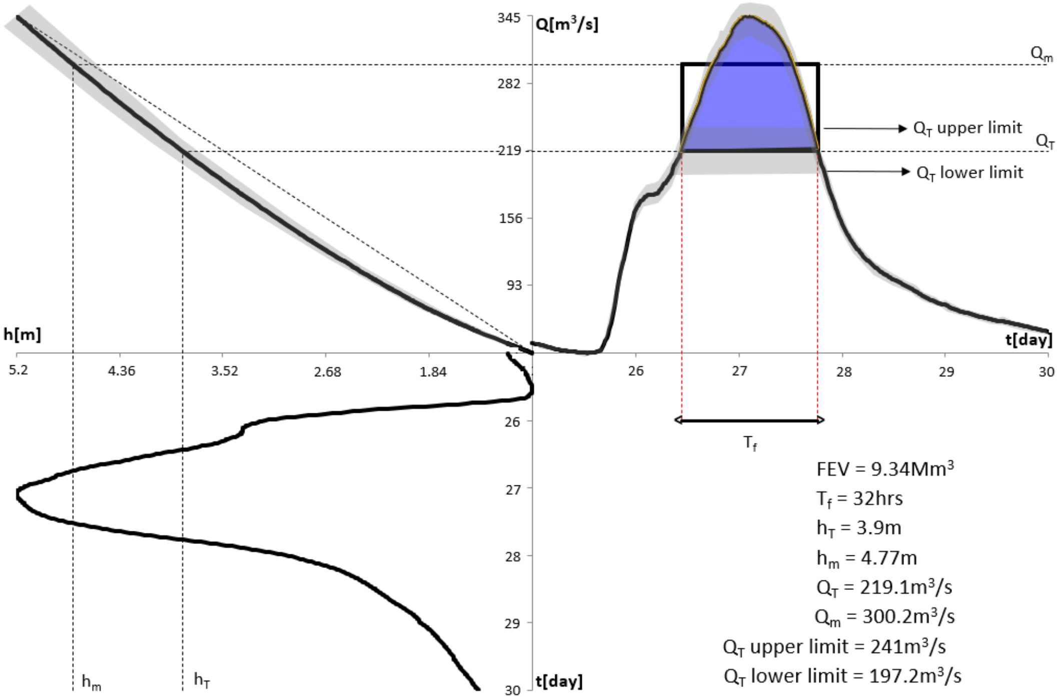

Figure 3.3: The quadrant plot for 2015 Boxing day flood of the River Aire at Armley. The rating curve can be seen on the upper left quadrant which calculated using equation **(3.1)** and coefficient from **Table 3.2**. The dash line on the rating curve is the linear approximation. The relationship river level $\bar{h}$ and the discharge level $Q(\bar{h})$ between the flood duration T_f which is 32 hours can be seen on the lower left and upper right respectively. Finally, the error rate 0.055 given by the EA is applied on rating curve, hydrograph and Q_T which shows by the shaded grey area.

Similar to Don River, the rating curve coefficients depend on the river height input. Nevertheless, Aire River only have 3 bounds. Using equation **(3.1)**, we can plug in the coefficients given by Environment Agency below,

j	h_{j-1} [m]	h_j [m]	a_j [m^{3-c}/s]	b_j [m]	c_j [-]
1	0.2	0.685	30.69	0.156	1.115
2	0.685	1.917	27.884	0.028	1.462
3	1.917	4.17	30.127	0.153	1.502

Table 3.2: The coefficient provided by the Environment Agency, the coefficients a_j, b_j, c_j varies between 3 bounds h_{j-1} and h_j. To decide, it depends on the river level $\bar{h}$ we choose to calculate which required for construct the rating curve.

Similar to previous analysis, by putting the corresponding FEV into an illustration of 2-metre-deep square lake. The recreation of the box can be seen below,

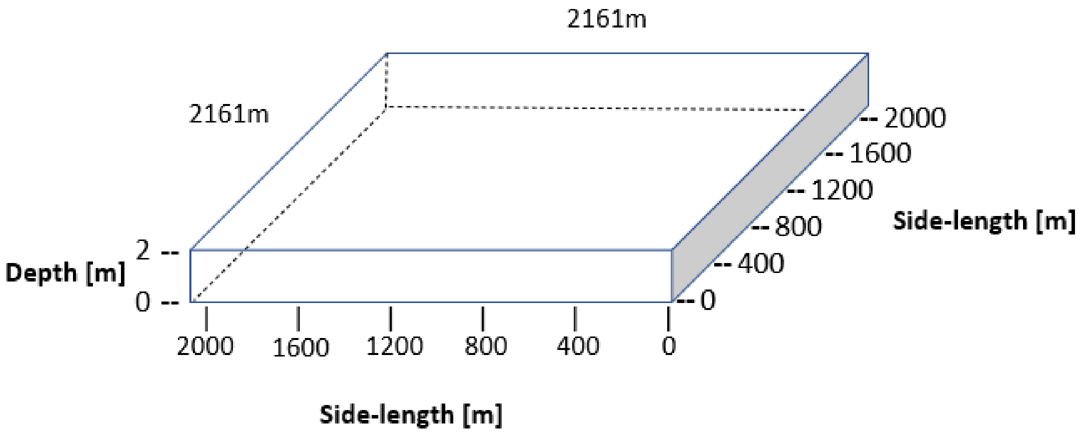

Figure 3.4: 2-metre-deep Square lake for Boxing day flood for River Aire from Armley monitoring station. The side length is 2161m each which calculated from $\sqrt{\frac{FEV}{2}}$.

Chapter 4

FEV Analysis on Ciliwung River

4.1 Overview

From introduction we had introduce Ciliwung river which flows from Mount Pangrango (Upstream) and ends up at Jakarta Bay (Downstream). Simultaneously, it also flows across 3 big cities (Bogor, Depok and Jakarta). Since, Depok city owned its floodgate for monitoring Ciliwung river and it is one of the big cities that suffers from huge flooding in the past. Therefore, we are going to investigate the flooding event in Depok City. Moreover, from the Ciliwung river map on Figure 1, we can spot that Depok is located fairly near downstream area. In fact, from the past research it has been found the reasons lead to the Depok flooding. One is excess river water which came from upstream due to heavy rain. Another reason is the downstream river capacity also experienced overflow due to the same heavy rain and most of the reservoir already full which cant contain any more water (Soemabrata, 2018). These excess water volume from upstream and downstream which has caused flooding in Depok city.

Figure 4.1: Flood occurred in Depok city on early 2020 that caused catastrophe among the locals.

The observation is going on the flood that happen recently on 1^{st} January 2020 across Bogor, Depok, Jakarta and area nearby. It was uncommon because it occurred specifically after the new year eve which is on 1^{st} January 2020. Since, people celebrate together and put some fireworks outside exactly on new year. However, due to the heavy rain the event is disrupted. At the worst, the rain was continuously fall which resulted floods in many areas include Depok.

Figure 4.2: Depok floodgate which monitors Ciliwung river level.

4.2 Data Collection and Analysis

4.2.1 Data Collection

First of all, there are compulsory data that is required at least to calculate the FEV which is the river level along with the time period ($\bar{h}$), flood threshold (h_T) and the river flow (if provided). In Indonesia there is open data website for the river level on the specific time which are uploaded by the department of Jakarta water resources.[6] The data include the information of the floodgate, river name, river level, time period, latitude, longitude, and the warning stage. Basically, there will be multiple river name (not only Ciliwung) and multiple floodgate that monitors corresponding river. The data can be downloaded and extracted as an excel file. Using the filter feature will help on filter and sort the data we wanted. Here, we require the height data of Ciliwung river on the Depok floodgate start from the 1st January 2020.

Next, from the **2.1.2**, we have the rating curve formula **(2.3)** with the input value for River Ciliwung which is,

$$Q(\bar{h}) = 11.403(\bar{h} - 0.2)^{1.715}.$$

This formula was obtained from paper, which use the hydrology analysis upon the Ciliwung

[6] Open Data of Indonesian rivers level can be accessed at https://data.jakarta.go.id/dataset/data-tinggi-muka-air-dki-jakarta-tahun-2020

river combined with the information from the environment agencies (Rahmasary, 2013). By plug in each height obtained from the excel file, we can receive the river flow for each height or rating curve.

We also need to find the flood threshold for the Depok floodgate. After some research, the Jakarta-flood statistic website[1] actually provides the analysis and graphic of the flood for rivers in Jakarta. They also state the specific river height for each warning stage. The warning stage consist of 4 stages, the 1^{st} stage as the worst stage (overflowing), 2^{nd} stage as the initial flood occur, 3^{rd} stage as the precaution stage and 4^{th} stage as the normal stage (no sign of there will potential flood). Since, flood threshold (h_T) is the height if the river when the flood happening, the 2^{nd} stage will be the suitable one to represent the h_T. By choosing the Depok floodgate or Ps. Depok on floodgate option, it tells the 2^{nd} stage is 270-280 cm. Therefore, 280 cm or 2.8 m are going to be the flood threshold for Ciliwung river from Depok floodgate.

4.2.2 Analysis of the Quadrant Plot

The analysis consists of three different plots to represent relationship between height vs time, height vs flow rate, and time vs flow rate. Using information and data that we have obtained in **4.2.1**, and process it in excel using VBA code, below is the result of the graph.

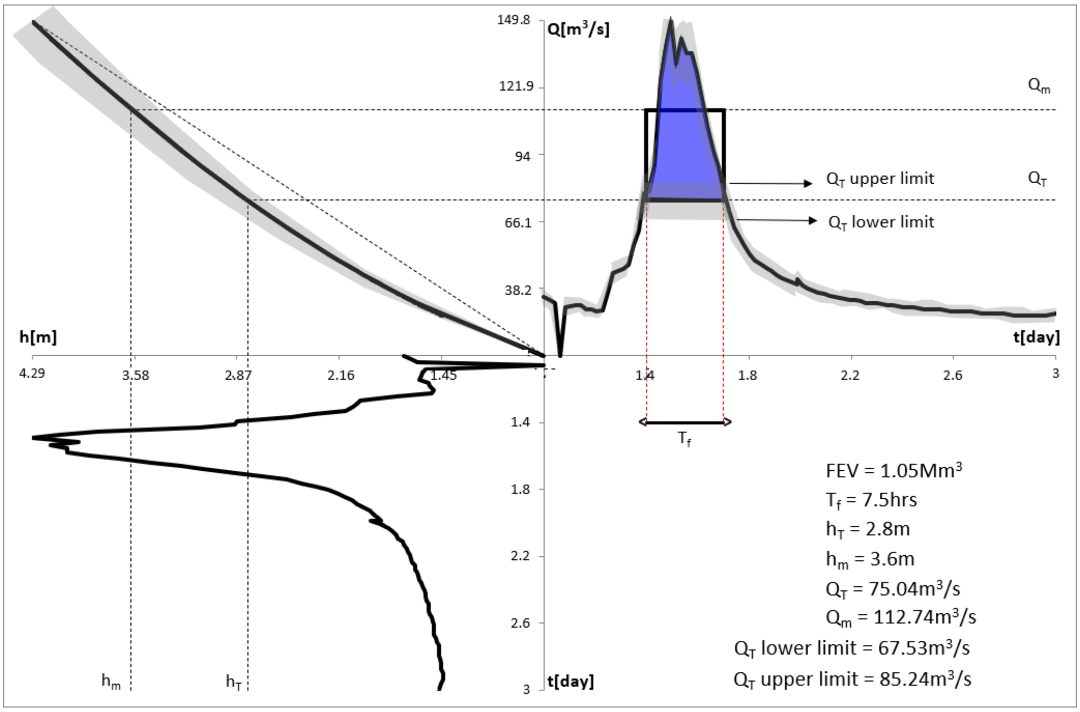

Figure 4.3: Quadrant plot for early 2020 new year flood of the River Ciliwung at Depok Floodgate. The plot shows 3-panel graph between relationship of time vs height (original data), height vs flowrate (rating curve), time vs flowrate (hydrograph).

[1]http://poskobanjirdsda.jakarta.go.id/Pages/grafikDataTinggiMukaAir.aspx

The bottom-left panel of **Figure 4.3** shows the relationship between time (in days) and the river Ciliwung height (in metre). The initial time 1 meaning it indicates the date turn to exactly 1^{st} January 2020 (00:00). As we can see, the chosen duration is within 3 days. The flood peaked at 4.29 m and starting from morning to evening of the 1^{st} January which accumulated duration equal 7.5 hours (T_f). The graph is plotted based on the data obtained from the department of Jakarta water resources website for 3 days. By plot normal line graph onto the data, the figure is generated.

Another quantity of interest in hydrology is the discharge value (Q), this is represented by the upper-left panel of **Figure 4.3**. Since the data of flow rate (Q) is not easily measured or provided. Therefore, by using rating curve approach might help to solve this issue. Basically, it is what constructed on this panel. By finding the discharge value which we know it has an input function of height $Q = Q(\bar{h})$ via rating curve formula that we obtained in **4.2.1**, we could obtain every flow rate value in each river level in a form of scatter plot. However, in the panel, since it is monotonically increasing, therefore by connecting every dot we can obtain the rating curve line (solid curve). The dashed line denotes the linear approximation of the rating curve. The grey shaded area represents the estimated error, which is expected to grow significantly for higher value of river level. The error rate we use is the default 0.1 or 10%.

Applying the rating curve panel into the Ciliwung river height data will result the discharge level on the time series. This can be seen from the upper-right panel of **Figure 4.3**, usually we call this as the hydrograph. This is the most important panel because here is where we calculate the FEV value. Since error rates exist on the rating curve, therefore we also project the error value in the hydrograph which was shown as the grey shaded area. Since the discharge level is in the volume per second, the area under the curve is just the volume of the water. If we analyse thoroughly, the FEV is the volume of excess water which is represented as the blue area under the curve. However, as we mentioned before, the FEV has three different approaches with vary accuracy. We also introduce the flood level threshold (h_T) which shows when the flood start occurs. This can be seen in term of the flood flow rate threshold (Q_T) via rating curve. Similarly, this also works for the mean of flood level (h_m) and mean flood flow rate threshold (Q_m). These results will be useful for one of the FEV approach by using the rectangle estimation. Moreover, the 10% error rate for the Q_T also stated to shows the worst and best case when the flood start occurs.

4.2.3 Result of FEV Estimation

As mentioned on the **2.1.1**, the flood threshold (h_T) can be seen from Jakarta-flood statistic website. Given the flood threshold for Ciliwung river is 2.8m. Next, the mean flood threshold (h_m) can be calculated by finding the average on all data points for the river height above h_T, which can be write as the equation below,

$$h_m = \frac{\sum_{j=1}^{M}(\bar{h}_j)}{j}, \forall h_j \geq h_T. \tag{4.1}$$

Where j is the number of the data points from 1 to M. Taking h_T = 2.8m, using **(4.1)** will give h_m = 3.6m. Another, constraint that we can obtain after determine h_T is the duration of the flood T_f. We know that the flood starts and stop occurs when the river reached 2.8m, and from the data it provides the duration of Ciliwung river flood on Depok floodgate in 1st January 2020 is 7.5 hours (from 9:10am to 16:10pm on 01/01/2020). The value of Q_T and Q_m are obtained through the rating curve which is 75.04 m^3/s and 112.74 m^3/s.

Using the information above we can estimate the FEV right away. From the least accurate FEV using equation **(2.10)** such as,

$$V_{e3} \approx 0.75Mm^3$$

Next, by equation **(2.6)** which represented as the area of rectangle in the graph. The FEV can be calculated as,

$$V_{e2} \approx 1.01Mm^3$$

Lastly, the most accurate FEV estimation (blue shaded region) using equation **(2.5)** is,

$$V_{e1} \approx 1.05Mm^3$$

From these results, we can compare all three FEV approximation formula. As the most accurate one V_{e1} the value is equal roughly 100% to the area of the blue shaded region in **Figure 4.3**. Next, using the equation **(2.6)** which yield V_{e2} show the value of FEV has 96.2% accuracy compare to V_{e1}. In other way, we can see it has 3.8% difference in the value which if we convert it into the volume will yield 0.04 Mm^3. This is a pretty fair value of the volume excess water. Finally, through equation **(2.10)**, it provides the estimate of V_{e3} that is 71.4% of the original FEV (V_{e1}). The difference volume is 0.3 Mm^3 which is quite significant amount of difference. Overall, we are going to use the most accurate estimation of FEV (V_{e1}) which is 1.05 Mm^3. This FEV choosing is important since we wish to mitigate the total FEV we obtained using various mitigation schemes.

Chapter 5

FEV Mitigation and Analysis

5.1 Graphical Representation of FEV

5.1.1 2-metre-deep square length

From the analysis, we are going to use 1.05 Mm^3 as the FEV value. Before to get in through the mitigation plan, we can express this volume into a 2-metre-deep square length with equally long side length. There is no main reason why 2 metre is picked as the depth of the container, we choose 2 metre depth because it is normal measure compare to the human height. Below, is the simple calculation to obtain the side length,

$$1.05Mm^3 \approx (2 \times 725^2 m^2)$$

For value of each side length is 725 metre. The graphical illustration which was generated in excel can be seen below,

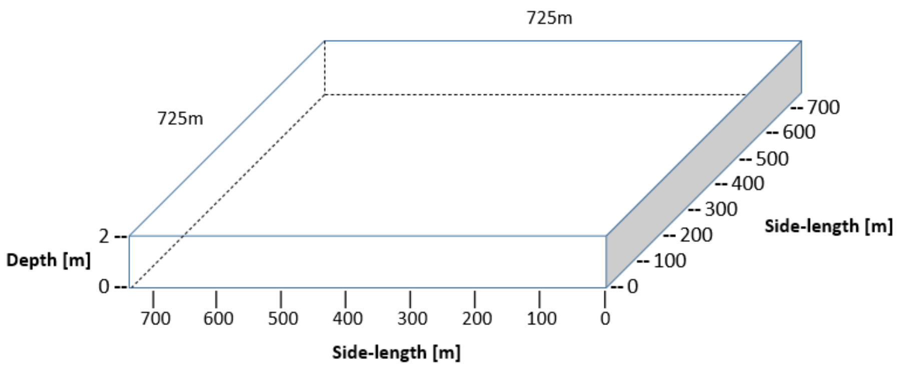

Figure 5.1: The FEV illustration of a container with 2 metre depth and 725×725 side length.

This result can be converted into 2-dimension which are going to be used for the mitigation plan illustration. So, the idea is we try to fill this 2-metre-deep square length with multiple mitigation schemes.

5.1.2 Correlation h_T with FEV and 2-metre-deep square

As we acknowledge that different flood threshold measurement (h_T) will yield different FEV value. There are some methods to alter the flood threshold, one of them is by building flood wall which might increase the value of the h_T. By building flood walls along the riverside which technically raise the flood threshold, it will prevent early flooding. Furthermore, since it will yield different FEV, therefore the 2-metre-deep square length will be different as well. The square side length will be adjusted based on the value of FEV. Hence, out of curiosity, using the excel (data) and VBA code (build the graph) we began model the correlation between h_T with FEV value (red line) and h_T with 2-metre-deep square length (blue line).

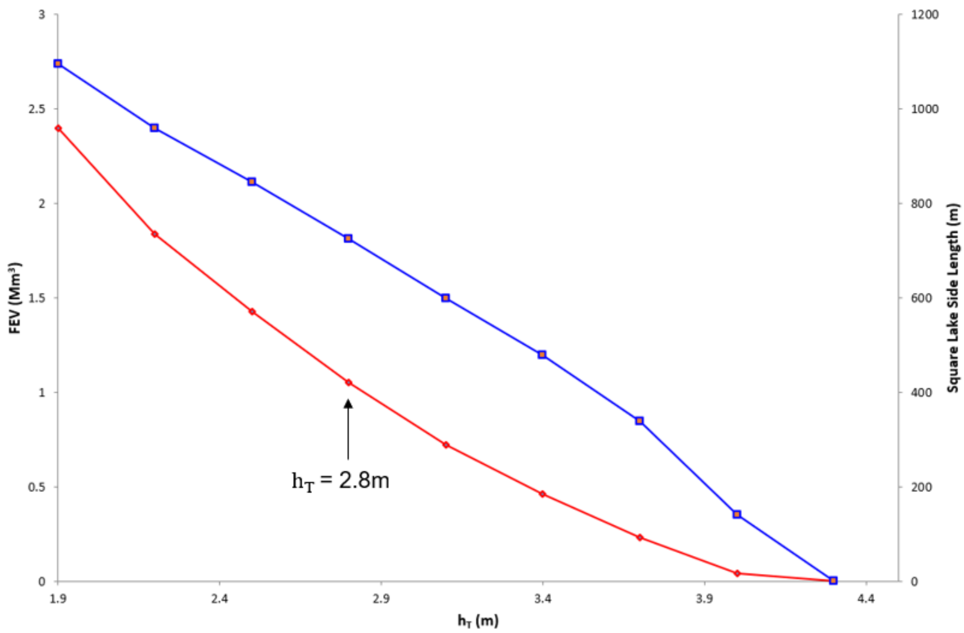

Figure 5.2: Relationship between choice h_T and corresponding FEV (red) and side length of a 2-metre-deep square surface (blue).

From **Figure 5.2**, it can be observed that with h_T equal to 2.8 metre the FEV has the value of 1.05 Mm^3 (red line) along with the 725 metre for the 2-metre-deep square length (blue line). This is going to be useful for building flood walls mitigation in the next section. We can identify by increasing certain value of h_T (flood walls height), there will be certain FEV value can be reduced.

5.2 Mitigation Alternatives and Cost Effectiveness

The mitigation scheme will be divided into 2 parts one is the proposed by government, the other is the hypothetical which is the alternative that come up with personal idea. We would like to find the cost for each percent of FEV (£/%) to check the most feasible solution in term of the mitigation schemes.

5.2.1 Proposed Mitigation

- **Ciawi and Sukamahi Dam**

  This plan was proposed since the post 2007 huge floods which has estimated economic loss at 8.6 trillion Rupiah (Asrafi *et al.*, 2019). Yet, the agreement of the project was finally signed and started on 23 November 2016 (Republika News, 2020). It is observed that the flood in Jakarta area mainly are due to heavy intensity of water flow that came from the upstream in short duration. The upstream can refer to the Ciliwung river which observed from Katulamapa Weir, Bogor city (Asrafi *et al.*, 2019). Therefore, these dams are built near upstream (Bogor city nearby) which controls 2 different sites of Ciliwung river.

  These dams are meant to be dry dams which means the function is not intended only to store water yet it will take the normal flow rate of the upcoming Ciliwung flow rate (Inflow) and using certain hydraulics model, it will reduce the flow rate of water when be release (Outflow). It is believed that dry dams have the best upstream retention for flood issue (Poulard, 2010). The effectiveness of the dry dam can be calculated using the how much water they can reserve and the difference between the river inflow and outflow. Below is the equation for the flood retention effectiveness formula,

  $$E = \frac{D}{I} \times 100\%. \tag{5.1}$$

  E stands for the effectiveness rate, D is the difference between river inflow and outflow (Inflow – Outflow), and I is the river inflow (in m^3/s) (Mardjono *et al.*, 2018).

  There is method to obtain the river outflow from the dams. Both dams have similar hydraulic method on how they remove the water from the reservoir. Basically, using the spill system which located on the dam body, the water can be removed in lower rate of flow (Mardjono *et al.*, 2018). In principle, the estimation relies on the discharge water that goes through the spill system with principle of conservation of the mass. Below is the formula for the discharge outflow after through the spill system,

  $$Q_{out} = C_d \times A \times v. \tag{5.2}$$

Q_{out} stands for the discharge through bottom outlet (Outflow in m^3/s), C_d is the discharge coefficient (here it is 0.6), A is the area of bottom outlet (in m^2), v is the water velocity through the bottom outlet (in m/s) (Mardjono *et al.*, 2018).

However, there could be the case that the dam is overflowing. Therefore, there is backup method using the overflow system which allows water to flow and melt through shrubs of a dam. The method can be calculated on the equation below,

$$Q_{over} = C_d \times L \times h^{3/2} \times v. \tag{5.3}$$

Q_{over} is the discharge over the weir (in m^3/s), C_d is the discharge coefficient (here it is 1.28), L is the weir width (in m), h is water height above the weir (in m), v is the water velocity over the weir (in m/s) (Mardjono *et al.*, 2018).

Since, the construction of the dams received many interruptions which result in delay. It predicted to be fully functioned and finish around the end of year 2020. Consequently, there is no past performance which can be used to gain the data of the effectiveness rate. However, by simulate the 100-year return period, the discharge inflow for each dam can be obtained below (Mardjono *et al.*, 2018),

		Discharge			
Name	Total Volume Available [Mm^3]	Inflow [m^3/s]	Outflow [m^3/s]	Flood Reduction [m^3/s]	Effectiveness rate [%]
Ciawi Dam	6.5	546.2	478.6	67.6	12.37
Sukamahi Dam	1.68	143.2	117.1	26.1	18.26

Table 5.1: The effectiveness of Ciawi and Sukamahi dam using calculation of 100-year return period, the effectiveness rate is calculated using equation **(5.1)**.

As we can see, the total effectiveness rate for both dams are about 30%. This means by simulate the calculation, 30% of FEV can be mitigated. This is also supported by the article from Ekonomi-Bisnis (2020) which stated the total effectiveness of Sukamahi and Ciawi dams are 30%.

The total cost for Ciawi Dam is estimated £131M and Sukamahi Dam is estimated £17M (Liputan 6 News, 2019). The cost is divided into 2 ways which is construction and excavate land, the combined construction and land cost is around £66M and the combined excavate area cost around £82M. (@1 GBP = Rp 18,159)

As the total FEV volume from the Depok floodgate is 1.05 Mm^3, the total storage of both dams combined are more than enough which is 7.73 Mm^3 to store the FEV water (**Table 5.1**). In addition. in case it is overflow it has the overflowing system to estimate the surplus water. Therefore, the dam is quite reliable to mitigate the upstream river water. However, in this case not all FEV that calculated previously came from the upstream river. Thus, it is believed that the water that came from upstream Ciliwung should be less than 1.05 Mm^3. Since, there is no data of spread of volume water came from certain direction. We assume, the 30% of total FEV 1.05 Mm^3 could be mitigated. As the result, by dividing the cost £148M with 30%, giving the Sukamahi and Ciawi dam a cost of £4.9M per percentage for the mitigated FEV.

5.2.2 Hypothetical Mitigation

- **Flood Walls**

  The first hypothetical mitigation is built flood walls along the Ciliwung river from Pos Pantau Sekber Sahabat Ciliwung, downstream to the Depok floodgate (≈4.92km).

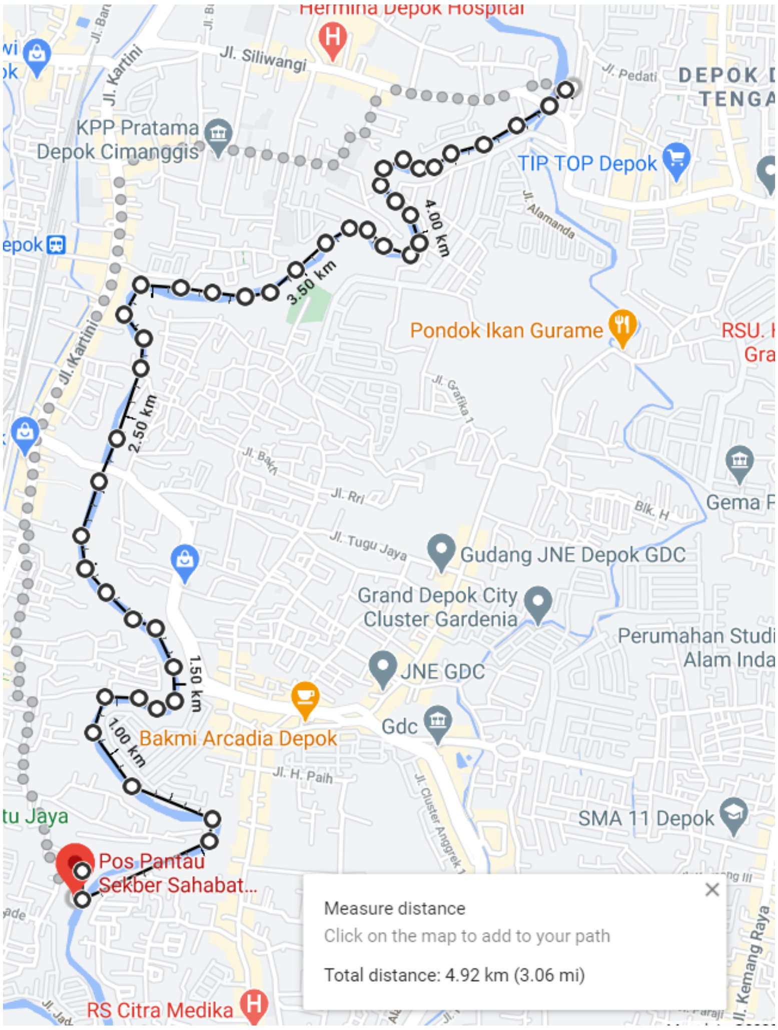

Figure 5.3: The total distance for build the walls generated by google maps.

The cost of building this flood walls is calculated using the costing of another similar floodwall which is built along the River Singkil. The total length of the flood walls is 26.5km and it costed around £18.5M (Serambi News, 2019). This give us £0.7/km, therefore for 4.92km it will cost £3.4M (@1 GBP = Rp 18,725). Using **Figure 5.2** we can find out how much FEV can be mitigated on the corresponding level increase in the flood wall. As we can see, the whole FEV will be mitigated (V_e = 0) when we raise the h_T to 4.3m. Similarly, if we increase 0.6m from current h_T (2.8m), it can be estimated 0.46 Mm^3 of FEV can be mitigated. This accounts 56% of the total FEV (1.05 Mm^3). As the result, by dividing £3.4M by 56%, giving building 0.6m floodwalls has cost of £0.06M per percentage of the mitigated FEV.

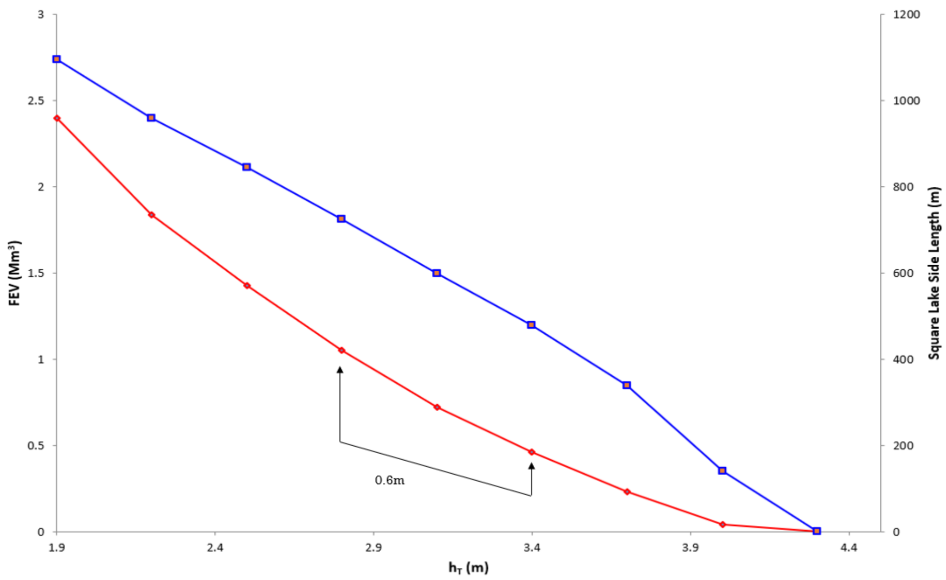

Figure 5.4: The total FEV of 0.46 Mm^3 is mitigated from increasing the h_T by 0.6m. This has the same concept of building floodwalls with the hight of 0.6m along the river.

- **Tree Planting**

  The second alternative is planting tree along the rivers and nearby. Tree planting has become well-known alternative for preventing flood in Indonesia. This practice has been applied on many areas for Ciliwung river especially the one that flows near Jakarta (Downstream). This prevention is believed has reduced a fair amount of excess flood water despite it is not enough.

  The target for this alternative is to mitigate the volume of 0.05 Mm^3 of the water which accounts for 4% of the total FEV. As mentioned in section **2.2.2**, a mature tree can absorb around 11,000 gallons in average for a single growing season (4 months). This leave each tree could absorb around 0.27 m^3 of water per day. To mitigate 50.000 m^3 of flood volume then it requires at least plant 144.000 trees. According to Republika News (2019), from the 2018 tree planting project for River Ciliwung in Jakarta, the cost for planting 22.000 trees is £0.176M which gives 1 tree cost £8 (@1 GBP = Rp 19,633). Therefore, the costing for 144.000 trees is £1.15M. This corresponds to 4% of the Ciliwung floods at Depok. This also yields £0.29M per percentage of the FEV mitigated.

- **Floodways**

  The final hypothetical scheme is building floodways which function to transfer water at certain speed from one river that experience flood to another common river which has larger volume to store water or a reservoir lake. Since it is built underground, the scenario for this alternative is going to be the floodways activates (open) when flood occurs on River Ciliwung. The excess water will go through this flood tunnel at the speed of 60 m^3/s and end up at the East Flood Canal (KBT) where we have introduced on the **1.2.2**. However, it is not simple to transfer the water directly at once to the East Flood Canal, therefore the water from Ciliwung river needs to go through and release at River Cipinang before being sent to the East Flood Canal. Since River Cipinang has better flood tolerance, therefore it is chosen as flood water storage that came from another rivers.

  The architecture of floodways will be like a huge underground pipe. The cost consists of the construction and excavate land for the pipe entry and exit. The construction from another similar project is estimated will cost around £3.05M (Kompas News, 2020). The excavate land will take cost which is £152 per m^2 of the land and it requires 10.357 m^2 to be removed which cost about £1.58M. Therefore, the total cost for to build floodways is around £4.63M. (@1 GBP = Rp 19,633)

  Since the Flood East Canal are built specifically to prevent flood, it is accommodated with drainage systems and with an extremely large volume of water storage. Therefore, it is reliable to be the last stop of the floodways. Additionally, with huge amount of capacity, the calculation to reduce the FEV will only consider the flow rate of water inside the tunnel and duration to mitigate the flood water.

  For the first scenario, with remaining FEV of 0.105 Mm^3 which accounts for 10% of total FEV we obtained. As the flowrate is 60 m^3/s, the duration for transferring much water can be calculated. Divide 0.105 m^3 by 60 m^3/s will give the duration in seconds which is 1750.75 second $\approx$ 0.49 hours. Accordingly, the cost per percentage for this scenario is £4.63M/10% = £0.46M/% for the FEV mitigated with duration of 0.49 hours.

  For the second scenario, we will fully use this mitigation scheme only to mitigate the total of FEV (1.05 Mm^3). Similarly, with the flowrate 60 m^3/s, the duration to drain the water out is estimated 17507 second $\approx$ 4.9 hours. The total cost of this scenario is similar to the first scenario which is £4.63M, despite that the cost per percentage for the scenario is £4.63M/100% = £0.046M/% for the FEV mitigated with duration of 4.9 hours.

5.3 Scenario of Flood Mitigation

5.3.1 First Scenario

Figure 5.5 shows the full mitigation of first flood scenario. The mitigation consists of build Ciawi and Sukamahi Dam, build 0.6m wall, planting trees and build floodways. This mitigation applies only for area nearby Depok Floodgate. Combining the 2-metre-deep lake illustration from **Figure 5.1** as the container for the plans and the cost effectiveness analysis from section **5.2**. Below illustration can be generated through excel,

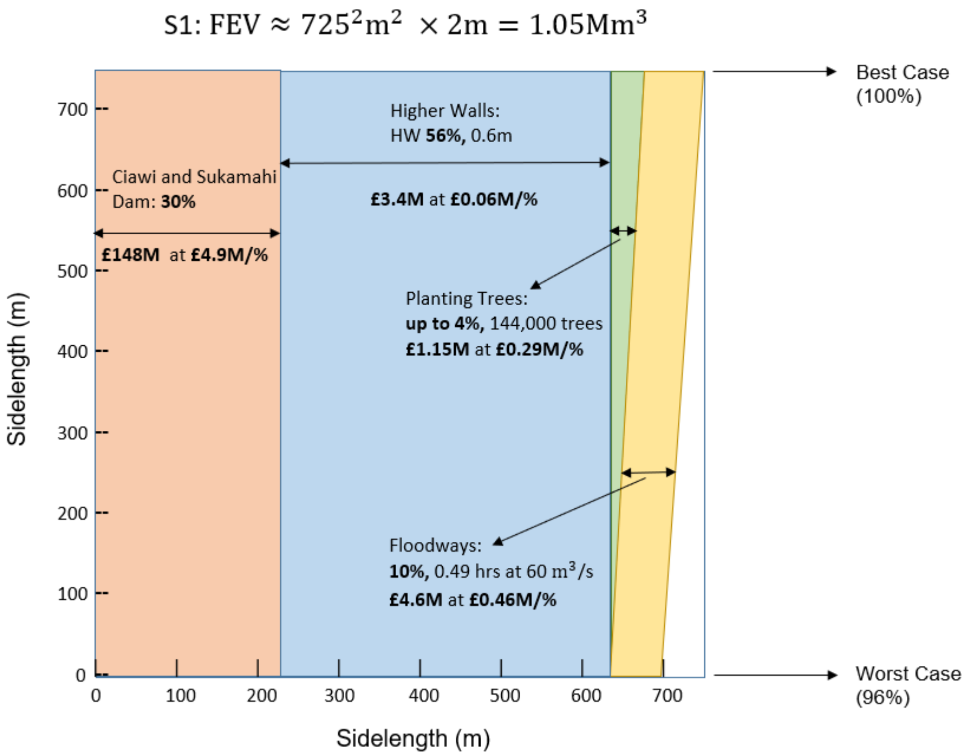

Figure 5.5: First flood mitigation scenario that mitigates 96% of the FEV in the worst and 100% at the best. Technically, Ciawi and Sukamahi Dam are specifically to mitigate excess water which came from upstream and the remaining scheme (higher walls, planting trees, floodways) are to mitigate the excess water near downstream.

Since tree planting is the natural mitigation, it depends on the nature condition which is uncontrollable. Therefore, it has to be put with the worst and best case in the scenario. Where the worst case the trees unable to absorb any water anymore and the best case is all the trees can absorb all 50.000 m^3 of the flood water. For floodways, it requires roughly 30 minutes to remove 10% of FEV water at 60 m^3/s flowrate.

5.3.2 Second Scenario

The second scenario only consist one plan which is the floodways. As mentioned in Floodways section from part **5.2.2**, the floodways are able to remove huge volume of water but in certain duration. The duration that requires this scenario to remove the total FEV is roughly 4.9 hours at 60 m^3/s.

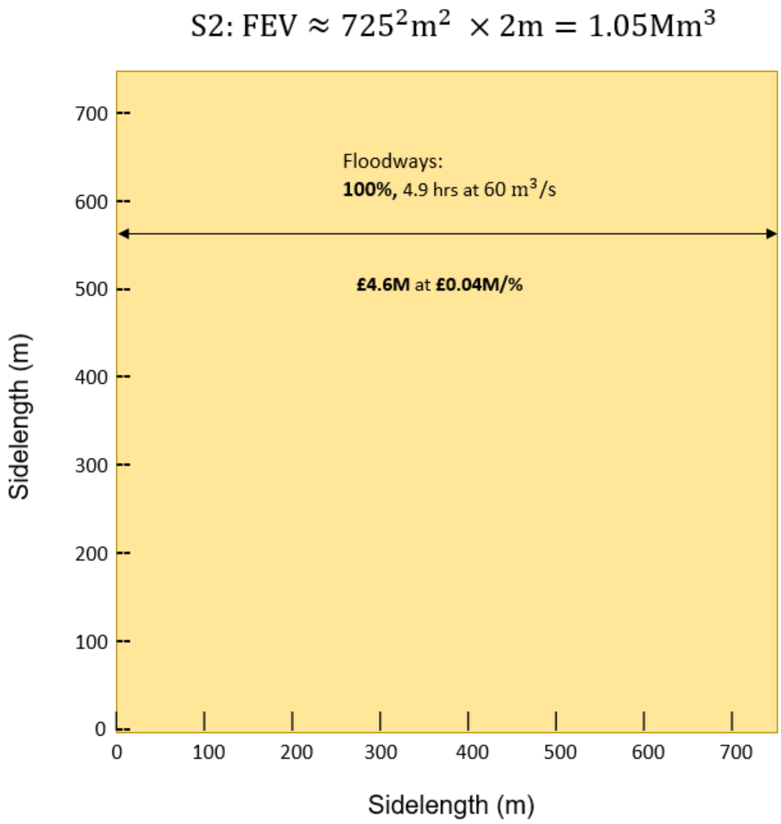

Figure 5.6: Second flood alternative scenario mitigates 100% of the FEV just with the floodways. Despite the low cost, however this mitigation relies heavily only on one mitigation.

Chapter 6

Discussion & Limitation

In this project, we have introduced FEV concept to deal with the flood analysis and used the result to come up with multiple flood mitigation alternatives. However, there should be drawback despite how flawless are the analysis. Since the model is all based on the value of h_T, which there is no certain estimation for it. It is possible that it will lead to inaccurate result of FEV, so it is important to get the value from a legitimate source. Despite that, several legitimate sources might still give deficiency on the hT value, but that value should be close enough to each other. Otherwise, more investigation and analysis are needed further. Another setback is on the mitigation plan analysis. Beside the cost and efficiency, there are actually more factors that need to be put on consideration for example, the social and environmental impact. In some cases, many projects have experienced delay due to fail on negotiation for relocating the local residents by the government. This disruption can be worse when the project is actually already done midway, where the government need to hold back the remnant from construction for certain period. For environmental issue, some project which requires large area like dam, canal or reservoir has actually cut off forest or tress to gain extra space. As mentioned above, trees could potentially be one of the mitigation alternatives to prevent flood. However, in some cases government prioritize more the man-made mitigation scheme instead of trees.

As one of the aims of this project is to find the most feasible alternative among the all the proposed mitigation schemes. It has been discovered that build flood wall has the most cost-effective flood mitigation measure. However, it is still not known if this wall is possible to be built along the river despite there is available space along the river. The 0.6m flood walls only cost £0.06M/%.

The second cost-effective scheme is planting 144,000 trees along the rivers or areas nearby with £0.29M/%. Even though it is pretty affordable, but it only covers 4% of total FEV and requires large land to plant these many trees. Therefore, it can be considered as not so cost-effective scheme.

Next is the floodways, despite it has £0.46M/% and only mitigate 10% of FEV. As mentioned in Floodways section from part **5.2.2**, it will give better rate of cost-effectiveness when more FEV are mitigated using floodways. With only concern of duration, this could potentially be cost-effective scheme if it is function in the correct way.

Lastly, the proposed mitigation that is by building Sukamahi and Ciawi dam has the highest cost per percentage with £4.9M/%. Regardless of the cost, these dry dams are meant to mitigate waters that came from upstream and it has combined storage up to 7.73 m^3 to store the upstream river inflow, where the waters are going to be released again in a short period with lesser flowrate. With these technologies and its crucial role, it is no doubt the high cost can be payoff with the effectiveness of this scheme. However, it can start function in the end of 2020.

By comparing the first and second scenario, the second scenario has much lower cost to propose. However, it is very risky by heavily rely on one scheme. Since it is man-made scenario, the floodways malfunction could occur anytime and the worst possible time is when the city is poured by heavy rain and flood occur. This might bring disaster since the only mitigation the locals have is the floodways. Therefore, it is better to diversify the plan (first scenario) even though it will cost much more. Beside it is less risky, it has perfect control on the excess water came from upstream and downstream river.

One limitation throughout this project is it took several months to obtain the river data to work on the analysis. Since this project period is on the pandemic situation, so it is required to work remotely. During pandemic, it is not possible to go to the current site to check the situation and meet staff face to face asking for question. Therefore, the communication is only available online via email which cannot be expected to obtain the answer right away. Another limitation is, since the excel code is adapted through code from python and R-studio, there are some feature that excel does not support. This has become one of the real struggles, as I need to come up with alternative to plot the designated quadrant plot and codes.

Overall, regardless of the setback with FEV method, the estimation is pretty comprehensive and make strong sense to obtain key results like the FEV value. This result is very important as it will determine the upcoming proposed mitigation scheme and check the cost-effectiveness of each scheme. Further research on determining the exact hT could be done to perfect this FEV method. In addition, by learning and understanding fluid dynamic also might help on some mitigation idea.

For further reading, the original idea of this paper is based on research of O. Bokhove, T. Kent and M. Kelmanson. It may find useful to read on these resources which is cited on below reference list[7] [8]. Furthermore, to check and edit the entire work code for this project, the reader can access through this webpage (`https://github.com/obokhove/floodproject5872math/tree/master/NicoSeptianus`). Alternatively, only the River Ciliwung quadrant plot code is provided on the appendix, however to see fully and run the codes, it requires the data which can be accessed from the Github webpage.

[7] On using flood-excess volume in flood mitigation, exemplified for the River Aire Boxing Day Flood 2015. Available at https://eartharxiv.org/stc7r/

[8] Communicating (nature-based) flood-mitigation schemes using flood-excess volume. Available at https://onlinelibrary.wiley.com/doi/pdf/10.1002/rra.3507

Bibliography

Asrafi, M., Anggraheni, E. and Sutjiningsih, D. (2019) *Influence of Ciawi and Sukamahi dam construction on flood early warning system in Katulampa Weir*. EDP Science [Online]. Available at: https://www.matec-conferences.org/articles/matecconf/pdf/2019/25/matecconf_icancee2019_04016.pdf (Accessed: 24 July 2020)

Bokhove, O., Kelmanson, M.A. and Kent, T. (2018) *On using flood-excess volume in flood mitigation, exemplified for the River Aire Boxing Day Flood 2015* [Online]. Available at: https://eartharxiv.org/stc7r/ (Accessed: 29 June 2020)

Bokhove, O., Kelmanson, M.A., Kent, T., Piton, G. and Tacnet, J.M. (2019) *Communicating (nature-based) flood-mitigation schemes using flood-excess volume*. River Res Applic, 35, pp. 1402-1414 [Online]. Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1002/rra.3507 (Accessed: 2 July 2020)

Brinkman, J.J. and Hartman, M. (2008) *Jakarta Flood Hazard Mapping Framework*. World Bank Report, Jakarta [Online]. Available at: https://edepot.wur.nl/140833 (Accessed: 7 July 2020)

Case, M., Ardiansyah, F. and Spector, E. (2007) *Climate Change in Indonesia Implications for Humans and Nature*. World Wide Fund for Nature [Online]. Available at: https://www.researchgate.net/publication/237325800_Climate_Change_in_Indonesia_Implications_for_Humans_and_Nature (Accessed: 29 June 2020)

Climate Technology Centre & Network (2017) *Flow-through dams* [Online]. Available at: https://www.ctc-n.org/resources/flow-through-dams (Accessed: 13 July 2020)

Ekonomi-Bisnis (2020) *Pembangunan Proyek Bendungan Terganjal Pembebasan Lahan* (Indonesian). [Online]. Available at: https://ekonomi.bisnis.com/read/20200210/45/1199689/pembangunan-proyek-bendungan-terganjal-pembebasan-lahan (Accessed: 21 August 2020)

Fachrul, M.F., Hendrawan, D. and Sitawati, A. (2007) *Land Use and Water Quality Relationship In the Ciliwung River Basin, Indonesia*. Trisakti University [Online]. Available at: https://www.researchgate.net/publication/317644604_LAND_USE_AND_WATER_QUALITY_RELATIONSHIPS_IN_THE_CILIWUNG_RIVER_BASIN_INDONESIA (Accessed: 2 July 2020)

Forstall, R.L., Greene, R.P. and Pick, J.B. (2009) *Which are the largest? Why list of major urban areas vary so greatly*. Tijdschrift voor Economische en Sociale Geografie, 100(3), pp. 277-297 [Online]. Available at: https://www.researchgate.net/publication/46541362_Which_are_the_largest_Why_lists_of_major_urban_areas_vary_so_greatly (Accessed: 5 July 2020)

Green, A.A., Whitehouse, G. and Outhet, D. (2007) *Causes of flood streamlines observed on Landsat images and their use as indicators of floodways*. International Journal of Remote Sensing, 4(1), pp. 5-16 [Online]. Available at: https://www.tandfonline.com/doi/pdf/10.1080/01431168308948527 (Accessed: 17 July 2020)

Kompas News (2020) *BBWSCC Siapkan Rp 60 Milliar untuk Pembebasan Lahan Sodetan Ciliwung* (Indonesian) [Online]. Available at: https://megapolitan.kompas.com/read/2020/01/15/21364851/bbwscc-siapkan-rp-60-miliar-untuk-pembebasan-lahan-sodetan-ciliwung?page=all (Accessed: 2 September 2020)

Liputan 6 News (2019) *Proyek Bendungan Ciawi dan Sukamahi Selesai 2020* (Indonesian) [Online]. Available at: https://www.liputan6.com/bisnis/read/3954076/proyek-bendungan-ciawi-dan-sukamahi-selesai-2020 (Accessed: 20 August 2020)

Mardjono, A., Juwono, P.T., Limantara, L.Y. and Suhartanto, E. (2018) *Effectivity of Kiwi and Sukamahi Dam on Jakarta Flood Control*. International Journal of Engineering and Technology [Online]. Available at: https://www.researchgate.net/profile/Ery_Suhartanto/publication/327514036_Effectivity_of_kiwi_and_Sukamahi_dam_on_Jakarta_flood_control/links/5e79c4114585158bd501c931/Effectivity-of-kiwi-and-Sukamahi-dam-on-Jakarta-flood-control.pdf (Accessed: 13 July 2020)

Mohsin, A. (2015) *Jakarta Under Water: The 2007 Flood and The Debate on Jakarta's Future Water Infrastructure*. Jurnal Wilayah dan Lingkungan, 3(1), pp. 39 [Online]. Available at: https://www.researchgate.net/publication/298429850_Jakarta_Under_Water_The_2007_Flood_and_The_Debate_On_Jakarta's_Future_Water_Infrastructure (Accessed: 13 July 2020)

Poulard, C., Leblois, L., Narbais, D. and Chennu, S. (2010) *Towards objective design of dry dams at watershed scale: how to take into account the spatial structure of the rainfall and its variability*. Balwois 2010, France [Online]. Available at: https://hal.archives-ouvertes.fr/file/index/docid/483012/filename/LY2009-PUB00026539.pdf (Accessed: 24 July 2020)

Rahmasary, A.N. (2013) *Analisa Hidrologi Bendung Katulampa: Potensi Pengembangannya Sebagai Bendungan Pengendali Banjir Jakarta* (Indonesia). Institute Pertanian Bogor [Online]. Available at: https://adoc.pub/analisis-hidrologi-bendung-katulampa-potensi-pengembangannya.html (Accessed: 29 June 2020)

Ratnaningsih, D. et al. (2019) *Water pollution trends in Ciliwung River based on water quality parameters*. Institute of Physics [Online]. Available at: https://www.researchgate.net/publication/337994281_Water_pollution_trends_in_Ciliwung_River_based_on_water_quality_parameters (Accessed: 29 June 2020)

Republika News (2018) *PLN Alokasikan Rp 3.19 Miliar Tanam 22 Ribu Pohon* (Indonesian) [Online]. Available at: https://republika.co.id/berita/piwjoc368/pln-alokasikan-rp-319-miliar-tanam-22-ribu-pohon (Accessed: 2 September 2020)

Republika News (2020) *Menanti Bendungan Ciawi-Sukamahi* (Indonesian) [Online]. Available at: https://nasional.republika.co.id/berita/q3ic44415/menanti-bendungan-ciawisukamahi (Accessed: 20 August 2020)

Sedlar, F. (2016) *Inundated Infrastructure: Jakarta's Failing Hydraulic Infrastructure. Michigan Journal of Sustainability*. 4 [Online]. Available at: https://quod.lib.umich.edu/cgi/t/text/idx/m/mjs/12333712.0004.004/--inundated-infrastructure-jakartas-failing-hydraulic?rgn=main;view=fulltext (Accessed: 7 July 2020)

Serambi News (2019) *Sudah Empat Hari Singkil terendam, Apa Kabar Mega Proyek Tanggul Penahan Banjir?* (Indonesian) [Online]. Available at: https://aceh.tribunnews.com/2019/12/09/sudah-empat-hari-singkil-terendam-apa-kabar-mega-proyek-tanggul-penahan-banjir?page=all (Accessed: 1 September 2020)

Soemabrata, J., Zubair, A., Sondang, I. and Suyanti, E. (2018) *Risk Mapping Studies of Hydro-Meteorological Hazard in Depok Middle City*. International Journal of GEOMATE, 14(44), pp. 129-133 [Online]. Available at: https://www.geomatejournal.com/sites/

default/files/articles/128-133-3730-Jachrizal-April-2018-g2.pdf (Accessed: 24 July 2020)

Steinberg, F. (2007) *Jakarta: Environmental problems and sustainability*. Habitat International, 31(3), pp. 354-365 [Online]. Available at: https://d1wqtxts1xzle7.cloudfront.net/34626979/HAB705_Jakarta_environment_and_sustainability.pdf?1409826693=&response-content-disposition=inline%3B+filename%3DHAB705_Jakarta_environment_and_sustainab.pdf&Expires=1599506560&Signature=T9888PAXkMiSGazTHE7ClZkj6LyPi5muOngj-bzCFQw8MTjLWniMjhBgyVcHZC8elTm5rA~zEghcuIIZdYQ7pQoX5kBNePClQEuLAjspetW-djbTOR37i4f2xgV0jIJaTJknieSuCPoFIXSs4xnqBORH0u1J6tlDujdx3GFJRyyV5mc7yhWQxmqcuXSf5xgBX5tRolCmsDNmbEaVO8K8n3mf3JEZGXsu1jvPDu3bMAMI2iFe5qf5lN9qFXGtw-p9DG2n3XzLr6KsE5WrB1jIzqHvtsrMjx~pxjZNQaOpI5aNA7bjR2R54lecqrmoBjR-bOWMq-7T8~CBMoX1j4a8Q__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA (Accessed: 7 July 2020)

The Yorkshire Post (2017) *The fight to protect Sheffield from repeat of deadly floods of 2007* [Online]. Available at: https://www.yorkshirepost.co.uk/news/fight-protect-sheffield-repeat-deadly-floods-2007-1774918 (Accessed: 1 August 2020)

World Health Organization (2007) *Floods in Jakarta, Banten, and West Java Province, Republic of Indonesia*. Emergency Report #6 [Online]. Available at: https://www.who.int/hac/crises/idn/sitreps/indonesia_floods_jakarta_province_19feb2007.pdf?ua=1 (Accessed: 5 July 2020)

Appendix

Complete Four Quadrant Plot

```
Sub equation2()
    Dim day As Range
    Dim flow As Range
    Dim height As Range
    Dim dayval() As Variant
    Dim flowval() As Variant
    Dim heightval() As Variant

    'Set day = Worksheets(1).Range("A2:A51")
    'Set flow = Worksheets(1).Range("B2:B51")
    'Set height = Worksheets(1).Range("C2:C51")

    Set day = Worksheets(1).Range("G2:G101")
    Set flow = Worksheets(1).Range("H2:H101")
    Set height = Worksheets(1).Range("I2:I101")

    dayval = day
    flowval = flow
    heightval = height

    'LBound(dayval)=1
    'UBound(dayval)=385

    a1 = WorksheetFunction.Min(day)
    'Debug.Print a1
    b1 = WorksheetFunction.Max(day)
    'Debug.Print b1
    c1 = (dayval(1, 1) - WorksheetFunction.Min(day)) / (WorksheetFunction.Max(day) -
    WorksheetFunction.Min(day))
```

```
'Debug.Print c1

'Insert value depend on the data (different river different data)
Dim a As Variant
Dim b As Variant
Dim c As Variant
Dim lowlims As Variant
Dim uplims As Variant
Dim ht As Variant
Dim error As Variant

ht = 2.8
a = 11.403
b = 0.2
c = 1.715
error = 0.1

Dim overht() As Variant
ReDim overht(UBound(heightval) + 1) '386
Dim length() As Variant
ReDim length(UBound(heightval)) '385
Dim hm As Variant

For i = LBound(heightval) To UBound(heightval)
overht(0) = 0
length(0) = 0
If height(i) >= ht Then
overht(i) = height(i) + overht(i - 1)
length(i) = 1 + length(i - 1)
Else
overht(i) = overht(i - 1)
length(i) = length(i - 1)
End If
Next i

hm = overht(UBound(heightval)) / length(UBound(heightval))

'Debug.Print overht(385)
'Debug.Print length(385)
```

```
'Debug.Print hm

Dim qt As Variant
Dim upper_qt As Variant
Dim lower_qt As Variant
Dim qm As Variant
Dim z As Integer
Dim q_upper() As Variant
ReDim q_upper(UBound(heightval))
Dim q_lower() As Variant
ReDim q_lower(UBound(heightval))

qt = a * (ht + b)  c
'Debug.Print qt

upper_qt = qt + 0.1 * qt
lower_qt = qt - 0.1 * qt

qm = a * (hm + b)  c
'Debug.Print qm

Dim flowrate() As Variant
ReDim flowrate(UBound(heightval)) '385
Dim scaledday() As Variant
ReDim scaledday(UBound(dayval)) '385
Dim scaledflow() As Variant
ReDim scaledflow(UBound(flowval)) '385
Dim scaledheight() As Variant
ReDim scaledheight(UBound(heightval)) '385
Dim scaledupper() As Variant
ReDim scaledupper(UBound(heightval))
Dim scaledlower() As Variant
ReDim scaledlower(UBound(heightval))

For i = LBound(dayval) To UBound(dayval) 'i = 1 to 50
flowrate(i) = a * (height(i) + b)  c
Next

For i = LBound(dayval) To UBound(dayval)
```

```
q_upper(i) = flowrate(i) + error * flowrate(i)
Next

For i = LBound(dayval) To UBound(dayval)
q_lower(i) = flowrate(i) - error * flowrate(i)
Next

'Debug.Print LBound(dayval)
'Debug.Print flowrate(100)

For i = LBound(dayval) To UBound(dayval)
scaledday(i) = (dayval(i, 1) - WorksheetFunction.Min(day)) / (WorksheetFunction.Max(day)
- WorksheetFunction.Min(day))
'Debug.Print scaledday(i)
Next i

For i = LBound(flowval) To UBound(flowval)
scaledflow(i) = (flowrate(i) - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))
'Debug.Print scaledflow(i)
Next i

For i = LBound(heightval) To UBound(heightval)
scaledheight(i) = (heightval(i, 1) - WorksheetFunction.Min(height)) / (WorksheetFunction.Max(height)
- WorksheetFunction.Min(height))
'Debug.Print scaledheight(i)
Next i

For i = LBound(heightval) To UBound(heightval)
scaledupper(i) = (q_upper(i) - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))
'Debug.Print scaledupper(i)
Next i

For i = LBound(heightval) To UBound(heightval)
scaledlower(i) = (q_lower(i) - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))
'Debug.Print scaledlower(i)
```

```
Next i

Dim negday() As Variant
ReDim negday(UBound(dayval)) '385
Dim negheight() As Variant
ReDim negheight(UBound(heightval)) '385
For i = LBound(dayval) To UBound(dayval) ' i = 1 to 385
negday(i) = -(scaledday(i))
Next
For i = LBound(heightval) To UBound(heightval) ' i = 1 to 385
negheight(i) = -(scaledheight(i))
Next

'Dim scaledht, scaledhm, scaledqt, scaledqm As Variant
scaledht = (ht - WorksheetFunction.Min(height)) / (WorksheetFunction.Max(height) -
WorksheetFunction.Min(height))
scaledhm = (hm - WorksheetFunction.Min(height)) / (WorksheetFunction.Max(height) -
WorksheetFunction.Min(height))
scaledqt = (qt - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate) -
WorksheetFunction.Min(flowrate))
scaledqm = (qm - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))

scaleupper = (upper_qt - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))
scalelower = (lower_qt - WorksheetFunction.Min(flowrate)) / (WorksheetFunction.Max(flowrate)
- WorksheetFunction.Min(flowrate))

Debug.Print ht, hm, qt, qm

'FEV
Dim FEV As Range
Dim FEVval As Variant
Set FEV = Worksheets(1).Range("M21")
FEVval = Round(FEV / 1000000, 2)

'Tf
Dim Tf As Range
Dim timeval As Variant
```

```
Set Tf = Worksheets(1).Range(”M24”)
timeval = Round(Tf, 2)

Dim xdata() As Variant
Dim ydata() As Variant
Dim negxdata() As Variant
Dim negydata() As Variant
Dim axa As Double
Dim aya As Double
Dim negd As Double
Dim negh As Double
Dim cht As Chart

’Plot the chart
Charts.Add
’ActiveChart.Name = ”chart”
’Set cht = Sheets(”chart”)
ActiveChart.Name = ”3-panel graph-readertest”
Set cht = Sheets(”3-panel graph-readertest”)

’d v Q
With cht
.ChartType = xlXYScatterLines
.SeriesCollection.NewSeries
ReDim xdata(UBound(dayval)) ’385
ReDim ydata(UBound(flowval)) ’385
For i = LBound(dayval) To UBound(dayval) ’ i = 1 to 385
axa = scaledday(i)
ReDim Preserve xdata(i)
xdata(i) = axa
aya = scaledflow(i)
ReDim Preserve ydata(i)
ydata(i) = aya
’Debug.Print xdata
Next i

.SeriesCollection(1).XValues = xdata
.SeriesCollection(1).Values = ydata
.SeriesCollection(1).Format.Line.Weight = 2.5
```

```
.SeriesCollection(1).MarkerStyle = xlMarkerStyleNone

.Axes(xlCategory).MinimumScale = -1
.Axes(xlCategory).MaximumScale = 1
.Axes(xlValue).MinimumScale = -1
.Axes(xlValue).MaximumScale = 1
.Axes(xlCategory).HasMajorGridlines = False
.Axes(xlValue).HasMajorGridlines = False
.Axes(xlCategory).TickLabels.NumberFormat = "[=-1]""4.29"";[=1]""3"""
.Axes(xlValue).TickLabels.NumberFormat = "[=-1]""3"";[=1]""149.8"""
.Legend.LegendEntries(1).Delete

'kiri axis
.Shapes.AddShape(msoShapeRectangle, 75, 243, 20, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(1).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 145, 243, 6.5, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(2).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 155, 243, 10, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(3).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 215, 243, 20, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(4).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 285, 245.2, 20, 7).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(5).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 355, 244.3, 10, 7.5).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(6).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 366, 244.3, 10, 7.5).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(7).Line.Visible = False

'kanan axis
.Shapes.AddShape(msoShapeRectangle, 425, 243, 7.5, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(8).Line.Visible = False
```

```
.Shapes.AddShape(msoShapeRectangle, 437, 243, 8.5, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(9).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 495, 243, 170, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(10).Line.Visible = False

'bawah axis
.Shapes.AddShape(msoShapeRectangle, 345, 265.2, 15, 170).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(11).Line.Visible = False

'atas axis
.Shapes.AddShape(msoShapeRectangle, 345, 235.2, 10, 4).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(12).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 350.5, 231.2, 5, 3.3).Fill.ForeColor.RGB =
RGB(192, 192, 192)
.Shapes(13).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 345, 133.2, 15, 70).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(14).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 345, 85.2, 15, 20).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(15).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 345, 50.5, 15, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(16).Line.Visible = False
.Shapes.AddShape(msoShapeRectangle, 345, 42.5, 15, 10).Fill.ForeColor.RGB =
RGB(255, 255, 255)
.Shapes(17).Line.Visible = False

'text kiri
.Shapes.AddTextbox(msoTextOrientationHorizontal, 70, 238, 40, 30).Select
Selection.Characters.Text = "3.58"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 140, 238, 40, 30).Select
Selection.Characters.Text = "2.87"
```

```
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 210, 238, 40, 30).Select
Selection.Characters.Text = "2.16"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 280, 238, 40, 30).Select
Selection.Characters.Text = "1.45"
Selection.Characters.Font.Size = 10.5

'text kanan
.Shapes.AddTextbox(msoTextOrientationHorizontal, 335, 270, 40, 30).Select
Selection.Characters.Text = "1.4"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 335, 316, 40, 30).Select
Selection.Characters.Text = "1.8"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 335, 361, 40, 30).Select
Selection.Characters.Text = "2.2"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 335, 407, 40, 30).Select
Selection.Characters.Text = "2.6"
Selection.Characters.Font.Size = 10.5

'text bawah
.Shapes.AddTextbox(msoTextOrientationHorizontal, 420, 238, 40, 30).Select
Selection.Characters.Text = "1.4"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 490, 238, 40, 30).Select
Selection.Characters.Text = "1.8"
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 560, 238, 40, 30).Select
Selection.Characters.Text = "2.2"
```

```
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 630, 238, 40, 30).Select
Selection.Characters.Text = ”2.6”
Selection.Characters.Font.Size = 10.5

’text atas
.Shapes.AddTextbox(msoTextOrientationHorizontal, 331, 180, 40, 30).Select
Selection.Characters.Text = ”38.2”
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 331, 134, 40, 30).Select
Selection.Characters.Text = ”66.1”
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 338, 89, 40, 30).Select
Selection.Characters.Text = ”94”
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 327, 41.2, 40, 30).Select
Selection.Characters.Text = ”121.9”
Selection.Characters.Font.Size = 10.5

.Shapes.AddTextbox(msoTextOrientationHorizontal, 62, 450, 30, 30).Select
Selection.Characters.Text = ”hm”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 13

.Shapes.AddTextbox(msoTextOrientationHorizontal, 149, 450, 30, 30).Select
Selection.Characters.Text = ”hT”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 13

.Shapes.AddTextbox(msoTextOrientationHorizontal, 710, 32, 40, 34).Select
Selection.Characters.Text = ”Qm”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 13

.Shapes.AddTextbox(msoTextOrientationHorizontal, 710, 101, 40, 34).Select
```

```
Selection.Characters.Text = ”QT”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 13

’kiri
.Shapes.AddTextbox(msoTextOrientationHorizontal, 0, 210, 50, 30).Select
Selection.Characters.Text = ”h[m]”
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True

’bawah
.Shapes.AddTextbox(msoTextOrientationHorizontal, 360, 450, 50, 30).Select
Selection.Characters.Text = ”t[day]”
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True

’kanan
.Shapes.AddTextbox(msoTextOrientationHorizontal, 720, 210, 50, 30).Select
Selection.Characters.Text = ”t[day]”
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True

’atas
.Shapes.AddTextbox(msoTextOrientationHorizontal, 360, 0, 60, 50).Select
Selection.Characters.Text = ”Q[m3/s]”
Selection.Characters(Start:=4, length:=1).Font.Superscript = True
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True

.Shapes.AddTextbox(msoTextOrientationHorizontal, 422, 268, 50, 30).Select
Selection.Characters.Text = ”<”
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True

.Shapes.AddTextbox(msoTextOrientationHorizontal, 480, 268, 50, 30).Select
Selection.Characters.Text = ”>”
Selection.Characters.Font.Size = 13
Selection.Characters.Font.Bold = True
```

```
.Shapes.AddTextbox(msoTextOrientationHorizontal, 449, 278, 50, 30).Select
Selection.Characters.Text = ”Tf”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 13

’Hasil tulisan
.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 300, 150, 30).Select
Selection.Characters.Text = ”FEV = ” & FEVval & ”Mm3”
Selection.Characters(Start:=13, length:=1).Font.Superscript = True
Selection.Characters.Font.Size = 15

.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 320, 150, 30).Select
Selection.Characters.Text = ”Tf = ” & timeval & ”hrs”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 15

.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 340, 150, 30).Select
Selection.Characters.Text = ”hT = ” & Round(ht, 2) & ”m”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 15

.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 360, 150, 30).Select
Selection.Characters.Text = ”hm = ” & Round(hm, 2) & ”m”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters.Font.Size = 15

.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 380, 150, 30).Select
Selection.Characters.Text = ”QT = ” & Round(qt, 2) & ”m3/s”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters(Start:=12, length:=1).Font.Superscript = True
Selection.Characters.Font.Size = 15

.Shapes.AddTextbox(msoTextOrientationHorizontal, 550, 400, 150, 30).Select
Selection.Characters.Text = ”Qm = ” & Round(qm, 2) & ”m3/s”
Selection.Characters(Start:=2, length:=1).Font.Subscript = True
Selection.Characters(Start:=13, length:=1).Font.Superscript = True
Selection.Characters.Font.Size = 15
End With
```

```
'h vs d
With ActiveChart
.SeriesCollection.NewSeries
ReDim negxdata(UBound(heightval)) '385
ReDim negydata(UBound(dayval)) '385
For i = LBound(dayval) To UBound(dayval) ' i = 1 to 385
negh = negheight(i)
ReDim Preserve negxdata(i)
negxdata(i) = negh
negd = negday(i)
ReDim Preserve negydata(i)
negydata(i) = negd
Next i

.SeriesCollection(2).XValues = negxdata
.SeriesCollection(2).Values = negydata
.SeriesCollection(2).Format.Line.Weight = 2.5
.SeriesCollection(2).MarkerStyle = xlMarkerStyleNone
End With

'h v Q (rating curve)
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(3).XValues = negxdata
.SeriesCollection(3).Values = ydata
.SeriesCollection(3).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(3).Format.Line.Weight = 2.5
.SeriesCollection(3).MarkerStyle = xlMarkerStyleNone
End With

'dash line
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(4).XValues = Array(0, -1)
.SeriesCollection(4).Values = Array(0, 1)
.SeriesCollection(4).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(4).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(4).Format.Line.Weight = 1
.SeriesCollection(4).MarkerStyle = xlMarkerStyleNone
```

```
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(5).XValues = Array(-scaledht, -scaledht)
.SeriesCollection(5).Values = Array(-1, scaledqt)
.SeriesCollection(5).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(5).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(5).Format.Line.Weight = 1
.SeriesCollection(5).MarkerStyle = xlMarkerStyleNone
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(6).XValues = Array(-scaledhm, -scaledhm)
.SeriesCollection(6).Values = Array(-1, scaledqm)
.SeriesCollection(6).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(6).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(6).Format.Line.Weight = 1
.SeriesCollection(6).MarkerStyle = xlMarkerStyleNone
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(7).XValues = Array(-scaledht, 1)
.SeriesCollection(7).Values = Array(scaledqt, scaledqt)
.SeriesCollection(7).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(7).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(7).Format.Line.Weight = 1
.SeriesCollection(7).MarkerStyle = xlMarkerStyleNone
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(8).XValues = Array(-scaledhm, 1)
.SeriesCollection(8).Values = Array(scaledqm, scaledqm)
.SeriesCollection(8).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(8).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(8).Format.Line.Weight = 1
```

```
.SeriesCollection(8).MarkerStyle = xlMarkerStyleNone
End With

'kiri merah
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(9).XValues = Array(1 / 5, 1 / 5, 1 / 5)
.SeriesCollection(9).Values = Array(scaledqt, scaledqm, -1 / 5)
.SeriesCollection(9).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(9).Format.Line.ForeColor.RGB = RGB(255, 0, 0)
.SeriesCollection(9).Format.Line.Weight = 1
.SeriesCollection(9).MarkerStyle = xlMarkerStyleNone
End With

'kanan merah
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(10).XValues = Array(105 / 300, 105 / 300, 105 / 300)
.SeriesCollection(10).Values = Array(scaledqt, scaledqm, -1 / 5)
.SeriesCollection(10).Format.Line.DashStyle = msoLineSysDash
.SeriesCollection(10).Format.Line.ForeColor.RGB = RGB(255, 0, 0)
.SeriesCollection(10).Format.Line.Weight = 1
.SeriesCollection(10).MarkerStyle = xlMarkerStyleNone
End With

'bawah item
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(11).XValues = Array(1 / 5, 105 / 300)
.SeriesCollection(11).Values = Array(-1 / 5, -1 / 5)
.SeriesCollection(11).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(11).Format.Line.Weight = 2
.SeriesCollection(11).MarkerStyle = xlMarkerStyleNone
End With

'curve for shaded area
Dim m1() As Variant
Dim m2() As Variant
Dim curv1 As Double
```

```
Dim curv2 As Double

With ActiveChart
.SeriesCollection.NewSeries
For i = LBound(dayval) + 20 To UBound(dayval) - 65 ' i = 1 to 385
curv1 = scaledday(i)
ReDim Preserve m1(i)
m1(i) = curv1
curv2 = scaledflow(i)
ReDim Preserve m2(i)
m2(i) = curv2
Next i
.SeriesCollection(12).XValues = m1
.SeriesCollection(12).Values = m2
.SeriesCollection(12).Format.Fill.ForeColor.RGB = RGB(120, 0, 0)
End With

'upper limit (rating curve)
With ActiveChart
.SeriesCollection.NewSeries
ReDim newxdata(UBound(heightval)) '385
ReDim newydata(UBound(dayval)) '385
For i = LBound(dayval) To UBound(dayval) ' i = 1 to 385
newupper = scaledupper(i)
ReDim Preserve newxdata(i)
newxdata(i) = newupper
newlower = scaledlower(i)
ReDim Preserve newydata(i)
newydata(i) = newlower
Next i
.SeriesCollection(13).XValues = negxdata
.SeriesCollection(13).Values = newxdata
.SeriesCollection(13).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(13).Format.Line.Weight = 2.5
.SeriesCollection(13).MarkerStyle = xlMarkerStyleNone
End With

'lower limit (rating curve)
With ActiveChart
```

```
.SeriesCollection.NewSeries
.SeriesCollection(14).XValues = negxdata
.SeriesCollection(14).Values = newydata
.SeriesCollection(14).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(14).Format.Line.Weight = 2.5
.SeriesCollection(14).MarkerStyle = xlMarkerStyleNone
End With

'upper limit
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(15).XValues = xdata
.SeriesCollection(15).Values = newxdata
.SeriesCollection(15).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(15).Format.Line.Weight = 2.5
.SeriesCollection(15).MarkerStyle = xlMarkerStyleNone
.SeriesCollection(15).Format.Line.Transparency = 0.3
End With

'lower limit
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(16).XValues = xdata
.SeriesCollection(16).Values = newydata
.SeriesCollection(16).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(16).Format.Line.Weight = 2.5
.SeriesCollection(16).MarkerStyle = xlMarkerStyleNone
.SeriesCollection(16).Format.Line.Transparency = 0.3
End With

'error qt upper
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(17).XValues = Array(1 / 5, 105 / 300)
.SeriesCollection(17).Values = Array(scaleupper, scaleupper)
.SeriesCollection(17).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(17).Format.Line.Weight = 2.5
.SeriesCollection(17).MarkerStyle = xlMarkerStyleNone
```

```
End With

'qrror qt lower
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(18).XValues = Array(1 / 5, 105 / 300)
.SeriesCollection(18).Values = Array(scalelower, scalelower)
.SeriesCollection(18).Format.Line.ForeColor.RGB = RGB(192, 192, 192)
.SeriesCollection(18).Format.Line.Weight = 2.5
.SeriesCollection(18).MarkerStyle = xlMarkerStyleNone
End With

'bikin kotaknya
With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(19).XValues = Array(1 / 5, 1 / 5)
.SeriesCollection(19).Values = Array(scaledqm, scaledqt)
.SeriesCollection(19).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(19).Format.Fill.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(19).Format.Line.Weight = 2.5
.SeriesCollection(19).MarkerStyle = xlMarkerStyleNone
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(20).XValues = Array(1 / 5, 105 / 300)
.SeriesCollection(20).Values = Array(scaledqm, scaledqm)
.SeriesCollection(20).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(20).Format.Line.Weight = 2.5
.SeriesCollection(20).MarkerStyle = xlMarkerStyleNone
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(21).XValues = Array(1 / 5, 105 / 300)
.SeriesCollection(21).Values = Array(scaledqt, scaledqt)
.SeriesCollection(21).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(21).Format.Line.Weight = 2.5
.SeriesCollection(21).MarkerStyle = xlMarkerStyleNone
```

```
End With

With ActiveChart
.SeriesCollection.NewSeries
.SeriesCollection(22).XValues = Array(105 / 300, 105 / 300)
.SeriesCollection(22).Values = Array(scaledqm, scaledqt)
.SeriesCollection(22).Format.Line.ForeColor.RGB = RGB(0, 0, 0)
.SeriesCollection(22).Format.Line.Weight = 2.5
.SeriesCollection(22).MarkerStyle = xlMarkerStyleNone
End With

End Sub
```

The Blue Shaded Area = Total FEV

```
Sub shadedarea()
    Dim myCht As Chart
    Dim mySrs As Series
    Dim Npts As Integer, Ipts As Integer
    Dim myBuilder As FreeformBuilder
    Dim myShape As Shape
    Dim Xnode As Double, Ynode As Double
    Dim Xmin As Double, Xmax As Double
    Dim Ymin As Double, Ymax As Double
    Dim Xleft As Double, Ytop As Double
    Dim Xwidth As Double, Yheight As Double

    Set myCht = ActiveChart
    Xleft = myCht.PlotArea.InsideLeft
    Xwidth = myCht.PlotArea.InsideWidth
    Ytop = myCht.PlotArea.InsideTop
    Yheight = myCht.PlotArea.InsideHeight
    Xmin = myCht.Axes(1).MinimumScale
    Xmax = myCht.Axes(1).MaximumScale
    Ymin = myCht.Axes(2).MinimumScale
    Ymax = myCht.Axes(2).MaximumScale

    Set mySrs = myCht.SeriesCollection(12)
```

```
Npts = mySrs.Points.Count

' first point
Xnode = Xleft + (mySrs.XValues(Npts) - Xmin) * Xwidth / (Xmax - Xmin)
Ynode = Ytop + (Ymax - mySrs.Values(Npts)) * Yheight / (Ymax - Ymin)
Set myBuilder = myCht.Shapes.BuildFreeform(msoEditingAuto, Xnode, Ynode)

Debug.Print Xnode
Debug.Print Ynode
' remaining points
For Ipts = 1 To Npts
Xnode = Xleft + (mySrs.XValues(Ipts) - Xmin) * Xwidth / (Xmax - Xmin)
Ynode = Ytop + (Ymax - mySrs.Values(Ipts)) * Yheight / (Ymax - Ymin)
myBuilder.AddNodes msoSegmentLine, msoEditingAuto, Xnode, Ynode
Next

Set myShape = myBuilder.ConvertToShape

With myShape
' USE YOUR FAVORITE COLORS HERE
.Fill.ForeColor.SchemeColor = 4
.Line.ForeColor.SchemeColor = 0
.Line.Weight = 1.5
.Fill.Transparency = 0.5
End With
End Sub
```