Tokyo's River Management System

Airi Tamura, Ayumi Sudo, Noa Kato, Sakuko Sugawara
Shibuya Senior High School, natsume@shibuya-shibuya-jh.ed.jp

Abstract

Tokyo is the most densely populated city in the world, housing over 13 million residents, but due to its climate and geography, Tokyo is very vulnerable to water disasters. Therefore, it is important that the city have a reliable water management system that can handle the high fluctuation in precipitation levels. One aspect of this water management system is the management of rivers to prevent flooding. In our essay, we took a local approach and focused on how Tokyo manages its rivers, looking at the intricate underground water management system called "Underground Water Palace", which takes in excess water from rivers and stores it underground. We analyse the benefits that is gained through the implementation of this system, but also its shortcomings such as high financial costs, specific geographical requirements, and the necessity for very high-level technologies. We then compare the metropolitan river management system with the systems in other cities, and go on to make several proposals for effective government leadership in river management for developing metropolitan cities.

Keywords

Metropolis, Water management, Stewardship and policy

Introduction

"Why is it that we've never faced serious flooding?" This was the question that started it all. As high school students who go to school in Shibuya, one of the most colorful and busy districts in Japan, this was a question that we had not seriously pondered before. The fact that we were still able to use the busy network of trains on the rainiest of days, the fact that all the rain water magically disappeared, and most importantly, the fact that we'd never seen the great rivers in Tokyo flood our cities despite the long typhoon seasons: all these things we took for granted, until we began researching about this topic. As we began our research, we found out that there is a massive underground channel -the Outer Metropolitan Area Discharge Underground Channel lying underneath the busy city, which are preventing river floods. We began to truly understand the significance of the large-scale river management system, which supports the safe living of millions of people. We would like to emphasize the remarkable technology of the underground channels, which lessens the damage of floods significantly. We wish to spread this river management system in order to enable a safer city for all people around the world.

1. The purpose of this investigation

Building city resilience is critical to the future of the Earth as more and more people live in big metropolitan centers. Many rapidly urbanizing cities have not been able to properly introduce systems to ensure safety from natural disasters. Even one of the most basic (and effective) methods – systematic control of rivers to prevent flooding, has been overlooked. The threat to residents and the wellbeing of cities is critical, and needs to be dealt with, quickly and efficiently. We believed that Tokyo, the most densely populated metropolitan city housing over 13 million people, was a good place to start looking for effective river management systems.

The purpose of this investigation is to uncover exactly how the world's biggest city manages its rivers in order to provide a safe environment for its citizens, to reveal the problems that remain and to suggest some possible solutions. Also, we will compare Tokyo's situation with other metropolises to consider ways that they can adopt some of Tokyo's water management policies, thus providing a local approach on the water management systems of metropolises. We hope that this investigation will help in promoting developing cities to adopt a well-functioning river management system to ensure safety of its citizens from water disasters.

2. Method of this investigation

Our main method of investigation will be through reading books, past records, Internet websites, and also analyzing past data. To supplement this, our team has done some fieldwork by actually going to see the underground water management systems and interviewing the people working at the Tokyo Waterworks department. We researched about the development of the river management system in Tokyo as a basis to propose ideas of how other countries can develop to be stronger to river floods and also industrialize at the same time.

3. Background Research

3.1 Risk of Water Disasters in Tokyo

3.1.1 Topography

Unlike most of Japan, which is on mountains, Tokyo is located on a flat plain called the "Kanto plain". It is the largest plain in Japan, and this plain covers more than 17,000km^2, which covers more than half of the Kanto region, which includes Tokyo, Saitama Prefecture, Kanagawa Prefecture, Chiba Prefecture, Gunma Prefecture, and Tochigi Prefecture. Whilst the West of Tokyo has comparatively higher, mountainous terrains, the east of Tokyo is on a lower level. Therefore it is easier for water to accumulate without streaming into rivers, and this makes the whole area more prone to flooding.

Figure 1: A map of the Kanto region[1]

3.1.2 Precipitation levels

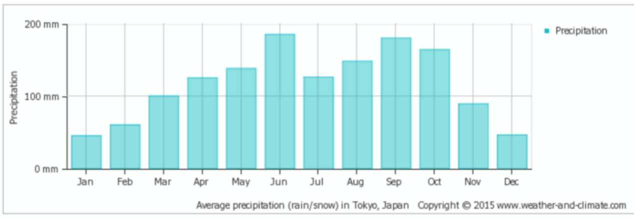

Figure 2: Monthly precipitation levels in Tokyo [2]

In Tokyo the annual rainfall averages approximately 1,530 millimeters [3]. The world average in annual rainfall is 880 millimeters, and Tokyo has approximately twice of the world average [4]. However, the precipitation level fluctuates greatly throughout the year. Tokyo and most of Japan experiences "tsuyu" which is a rainy season around June. During "tsuyu", warm and wet air from the south, and cold and dry air from the north collide and heavy rain falls consecutively for several weeks. Therefore, the danger of water disasters from rivers increases during this time. In addition, around September and October the precipitation level is high because of the typhoons, which arrive frequently. September's rainfall of 208.5mm is 5 times more than that of the driest month, December, which has a rainfall of only 39.6mm [5]. This extreme fluctuation, and excess in rainfall means that Tokyo is very prone to water disasters.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0	0	0	0	0	0.2	0.4	0.9	1.1	0.6	0	0	3.1

Figure 3: Number of typhoons that Tokyo faces per month [6]

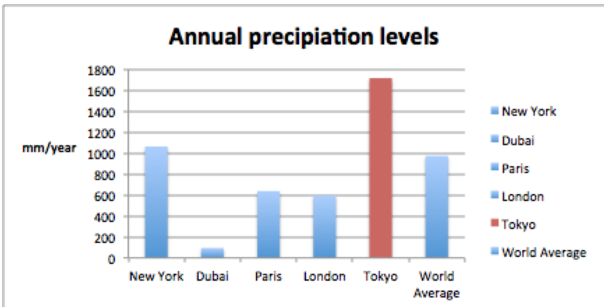

Figure 4: Comparison of Tokyo's precipitation levels with other major cities [7]

3.1.3 Rivers

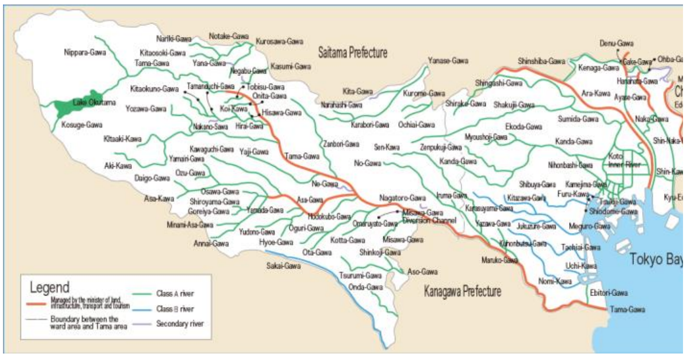

Figure 5: Map showing the rivers in Tokyo [8]
(The red line shows the rivers that are managed by the minister of and, infrastructure, transport and tourism.
The green rivers are Class A rivers, and the blue rivers are Class B Rivers)

Due to the mountainous terrain surrounding Tokyo, most rivers are short, with a steep slope, and have only small river basins. Therefore, when it rains very hard, the rivers quickly swell in size, reaching maximum capacity within a short time [8]. The rate of increase in the flow discharge is very large, with the Tone River discharging 100 times more water than its usual state during heavy rain, compared to the Mississippi River only growing a maximum of 3 times in flow discharge levels [9]. Rivers in Tokyo, and throughout Japan have the characteristic of rising and falling in water levels very quickly.

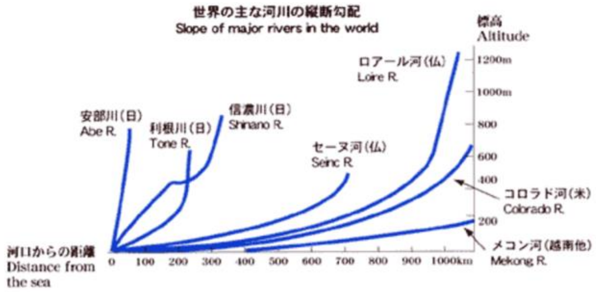

Figure 6: Graph showing the steep gradient of Japanese Rivers (red) as compared to rivers around the world (blue) [10]

Moreover, due to Tokyo's geographical features, many of the rivers in Tokyo are more elevated than the land in which people live [11]. Thus, high river levees are required to be built along the rivers. Yet, if these river levees were to break, the damage would be disastrous, as the rivers would easily flow into the residential areas.

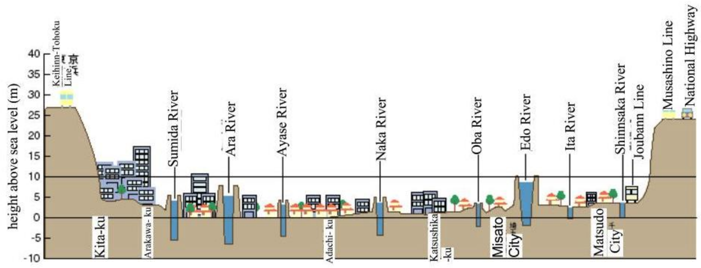

Figure 7: Graph of Tokyo's topographic profile, which shows the elevation of land in comparative to the elevation of the major rivers [12]

To make matters worse, due to the high economic growth which began in the 1960s, large portions of the population shifted to urban areas, and urbanization occurred in areas with very high risk of flooding. Today, 51% of the Japanese population, and 75% of properties are situated in alluvial plains, which only make up 10 % of the Japanese landmass. Therefore, the consequences of flooding would be catastrophic [13].

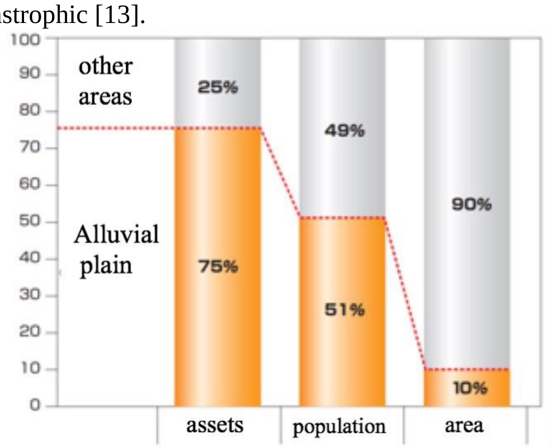

Figure 8: Graph showing the percentage of properties in alluvial plains [14]

3.1.4 Overall Risk

Overall, we can see that Tokyo is very prone to water disasters because of the high precipitation levels during the rainy seasons, and the characteristics of the rivers. In fact, Tokyo has the highest risk from being affected by natural disasters (earthquakes, tsunami, river floods, high tide disasters, and landslide disasters), out of all of the cities in the world [16]. In addition, in terms of the natural environment, Tokyo is the most vulnerable city to river flood disasters in Japan [17]. However despite this, Tokyo faces very few water disasters as compared to other metropolitan cities in the world. One important factor behind this is the outstanding river management system.

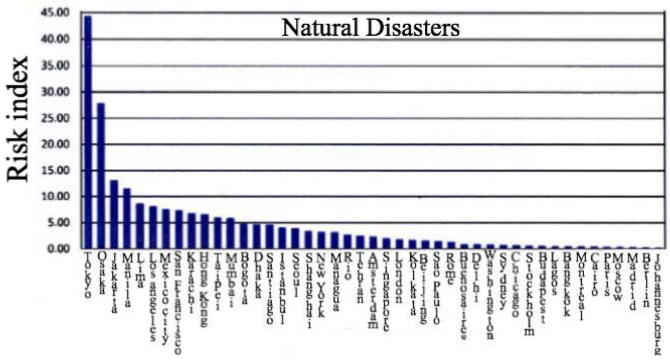

Figure 9: Graph showing that Tokyo has the highest Risk Index for natural disasters out of all the metropolitans in the world [18]

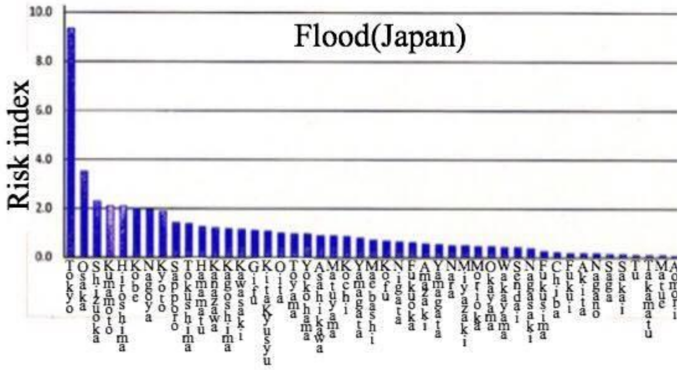

Figure 10: Graph showing that Tokyo is the city which is the most geographically prone to water disasters in Japan [19]

3.2 Development of Tokyo's River Management System

3.2.1 Overall History

Since floods have always been common, Japan had developed water management systems earlier than many parts of the world. The following is a brief timeline of the development of modern water management systems in Japan.

Meiji Era

Many floods occurred during the end of the 19th century. (e.g. Floods in the Yodogawa and Chikugogawa Rivers in 1885, the Chukugogawa River in 1889, the Tonegawa River in 1896). Irrigation systems were brought under the control of the Ministry of Interior instead of being managed by the municipal.

Japanese engineers who had travelled to European nations during the beginning of the Meiji Era began returning to Japan and spread new technology for irrigation. In 1896, the first River Law was passed in which the Ministry of the Interior became responsible for large-scale irrigation projects, allowing the Ministry of the Interior to directly administer designated rivers. In 1910, large-scale floods occurred across the nation, leading to more than 50 rivers becoming directly controlled by the government. Moreover, due to the increase in population, people began to live in hazardous areas that frequently experienced floods. The government ordered the construction of levees based on the belief that flood waters should be collected and contained in river channels so that it can be returned to the sea, which was different from the initial belief that urban areas and low flatlands should be prioritized by constructing levees primarily in such places. In order to protect larger areas from floods, river spans were expanded and dug deeper, and river levees were constructed.

Taisho Period to the Pre WWII Japan

The development of irrigation systems was prioritized along with the development of railways by the government throughout the Meiji Era to the beginning of the Showa Era. Three major channels in the Arakawa, Yodogawa, and the Shinanogawa Rivers were constructed during this period. The development of new waterways paved the way for industrialization in Japan, which was still very much primitive at the time. Due to this rapid industrialization, the population grew drastically thus leading to the urban development of the land surrounding the upper stream and the midstream of the rivers. The maximum water level and the amount of time it took water to recede changed, which can be seen from the example of the Tonegawa River, which supplies water for large areas of Tokyo. In 1900, the population was 44,000,000 but by 1950, the population grew to 83,000,000; within 50 years the population grew by 39,000,000. During this period, the maximum amount of water to flow in the river changed from 3,750m^3 per second in 1896 to 17,000 m^3 per second in 1947. The biggest causes of this drastic change were the deforestation and urbanization that deprived the region from trees, which used to serve as natural dams. The technology for the prevention of water disasters that Japan had during this period did not correlate to the rapid urbanization, so it can be said that Tokyo was at high risk of experiencing deadly floods during this period.

Post WWII Japan (A period of disasters)

During the 14 years from 1945 when the Makurazaki Typhoon occurred and to 1959 when the Isewan Typhoon and High Tide Disaster, apart from 2 years, the death toll from natural disasters exceeded 1,000 every year. The lengthy war had left the entire nation destructed and therefore made the towns vulnerable towards natural disasters. Moreover, the rapid industrialization that occurred at the wake of the war led to poor quality infrastructure.

3.2.2 Past Water Disasters

3.2.2.1 Meiji era's major water disaster

Much of the flatland in the Tokyo metropolitan area today was created by land reclamation and riparian improvement of mudflats and wetlands during the reign of the Tokugawa shogunate to make the area more habitable and accommodating. Thus, inevitably, Edo (Tokyo) is more prone to floods. Yet, the problem of flooding was never dealt with seriously even after Edo was severely damaged by floods in 1742. [20]
On the 5th of August 1910, due to the overlapping of the wet season rain front, as well as two separate typhoons, the Kanto area (Greater Tokyo) faced torrential rain. The Tonegawa River, the Arakawa River, and the Tamagawa river flooded (all of which are big rivers that flow through the Tokyo metropolitan area), and the river levees were completely useless in keeping the water from flowing into the cities. 769 people died, 78 people went missing, and over 4000 buildings were swept away. [21] The whole Kanto plain became submerged in water, which rose up to a meter.

3.2.2.2 Taisho era's high tide water disaster

The Taisho era's high tide water disaster was different from the Meiji era's water disaster in 1910 in the way that it was a storm surge disaster. The typhoon came when Tokyo was in its high tide, thus the biggest cause of the damage was the high waves. The water levels rose very high in a short time, therefore over 500 people died in Tokyo alone by drowning, and over 40,000 houses were completely demolished [22]. Many people were left homeless, and many people in the fishing industry died, or lost their ships, which gave the economy of Japan great damage.

3.2.2.3 The Typhoon Kathleen disaster

In September 1947, Typhoon Kathleen brought terrestrial rain to the Kanto region, with the total rainfall surpassing 500mm. As a result, the Tone river (the largest river to flow through the Tokyo metropolitan area,) flooded on a large scale. At its peak, over 17,000 tons of water was flowing past per second, which broke the record of 10,000 tons of water per second in 1935 [23]. This record breaking excess of water caused 350 meters of the flood levees to break, where the river water overflowed, causing heavy flooding of unprecedented levels [24]. Due to the fact that the river levees had not broken during the Taisho era's high tide water disaster, the strength of the effectiveness of the river levees was overestimated. In reality, the effectiveness of the river levees had deteriorated due to aggravating factors such as the annulment of the retarding basins in the upper streams due to development. This breaking of the river levees was the beginning of the Kathleen typhoon disaster.
The Tone river's current river channel does not follow the natural terrain, and was artificially altered to face East during the large-scale construction work which took place during the Edo period. Therefore, when the levees broke, the flood caused by the Kathleen typhoon followed the Tone River's original channel. Since the flood flow was very large in quantity, it broke the levees of the smaller rivers and by the morning of 19th, September, had reached the Tokyo metropolitan area, where it was finally drained into the Tokyo Bay through the Edogawa estuary. By then, the flood had flowed down a total of 60km, demolishing many buildings and drowning many people on its way. [25]
After the disaster caused by the Kathleen typhoon, the government conducted extensive projects to enhance flood control. In 1949, the flood control committee formulated the "Revised River Improvement Plan" with ten rivers as its target including the Tone River, in which dams would be created to regulate the floods.

3.2.2.4 Showa Tamagawa floods

The Showa Tamagawa floods occurred in September 1974 when strong typhoons hit Tokyo. Due to the overflow of the rivers, the river banks collapsed, which led to more than 20 houses being washed away by the strong river currents. In order to prevent further damages, the Self Defense Forces blew up some of the riverbanks as they were only exacerbating the floods by stopping the river water from flowing back into the river. [26]
In 1976, the residents of the houses that had been washed away by the floods sued the Japanese government for having been unable to manage the Tamagawa River properly. After a long process, the residents eventually won the trial and received compensation from the state.

3.3 Current River Management System in Tokyo

3.2.1 River Law

In 1997, changes were made from the previous law. The river law also covered the environment surrounding the river with the two other aspects. Also, instead of making mandatory that river managers create short term, basic plans for the implementation of construction works, Japan made mandatory that the river managers to work out the basic policy for river improvement on a long-term basis, and the step by step plan of river improvement in a span of twenty to thirty years [31].
The river law we have today, was last amended in 1997, and has been supporting many people's lives. The current river law covers up solutions to three main aspects; the prevention of river floods, the use of river water, and the environment around the rivers [30]. In addition, rivers are categorized into three levels, according to its importance. The river managing facilities are different for every level, but all of these facilities are called river offices in Japan. The river law mandates these river offices to work out the basic policy for maintaining the river on a long term basis. This basic policy has to include ways to prevent or lessen river floods, the appropriate use of the river water, and the maintenance and improvement of the environment surrounding the river. In addition to this basic policy, the river offices also has to work out a specific plan for river improvement, which can be accomplished within 20 to 30 years [31]. This plan has to include a goal for the three aspects and the details for river construction works. When making this plan, the citizens who live near the rivers has a say, and their opinions are able to be reflected. With the

basic policy and the specific plan, the river offices are able to prevent or lessen river floods, make a nice environment, and maintain the quality of the river water.
In Tokyo there are 127 rivers in total. Out of these rivers, 92 rivers were categorized as the level 1 Rivers and are managed by the MLIT. There are 15 rivers that are marked as level 2 rivers and are managed by the governor of Tokyo. The other 20 rivers are managed by the heads of municipalities [32]. Many different methods of maintenance and improvement are made for each river. However, Tokyo being a big city with many buildings and little land, the prevention of river floods is an important task for the river managers. The river managers have to find a solution that can lessen the damage of floods but still promote industrialization in that area.

3.2.2 The Outer Metropolitan Area Underground Discharge Channel

Currently "The Outer Metropolitan Area Underground Discharge Channel", which is a large underground discharge channel, protects the people living in the Metropolitan Area. These underground discharge channels are one of the world's largest and was constructed using world-class Japanese technologies. With these underground discharge channels and the remarkable control system; "The Metropolitan Area Outer Underground Discharge Channel" is able to provide safety and reassurance for the people.

3.2.2.1 The Edogawa River Office

The Outer Metropolitan Area Underground Discharge Channel is managed by the Edogawa River Office, which is part of the MLIT. This river office manages three rivers; the Edo River, the Naka River and the Ayase River. This river office has came up with a remarkable solution of making a town resistant to water disasters, but at the same time has managed to promote industrialization by making the Outer Metropolitan Area Underground Discharge Channel.

3.2.2.2 Why the Government implemented the Project

The Naka and Ayase River basin is on low-lying land surrounded by the Tonegawa river, Edogawa river, and the Arakawa river, and due to its flat topography, rainwater was unable to be effectively discharged into the river, meaning that the area was very prone to floods. Yet, this Naka and Ayase River basin area is a rapidly urbanizing area spanning over Tokyo, Saitama prefecture, and Ibaraki prefecture, with over 3.47 million inhabitants, and 56 trillion yen worth of assets [33]. Therefore, as an epochal and long lasting measure to control the floods, the government decided to build the metropolitan area outer fence flood control channel to drain the excess river water into Edo River, and to improve the degree of flood control in order to avoid flooding in the Naka River and Ayase River basin.

3.2.2.2 How it functions

The Metropolitan Area Outer Underground Discharge Channel consists of four parts; the "inflow facility" where the excess water flows in from the rivers, the tunnel where the water flow is slowed down in an underground space, the water pressure control tank, and the drainage facility. The Discharge Channel functions when typhoons and heavy rainfall lead to the rise in the water levels of the Naka and Ayase Rivers. Once the floodwater enters the "inflow facility", the water is collected in tanks. There are 5 tanks that are more than 60 meters deep, a size in which a space shuttle or the Statue of Liberty can easily fit. The water then flows through an underground tunnel and enters the Tank Number 1. The water pump in the drainage facility is operated by the surveillance room where employees work in shifts to keep an eye on water levels 24 hours a day. The water drained will then be returned back to the Edo River after the weather improves. The drainage pipes are capable of draining 200 m^3 of water per second, which is the amount of water in a 25-meter pool.

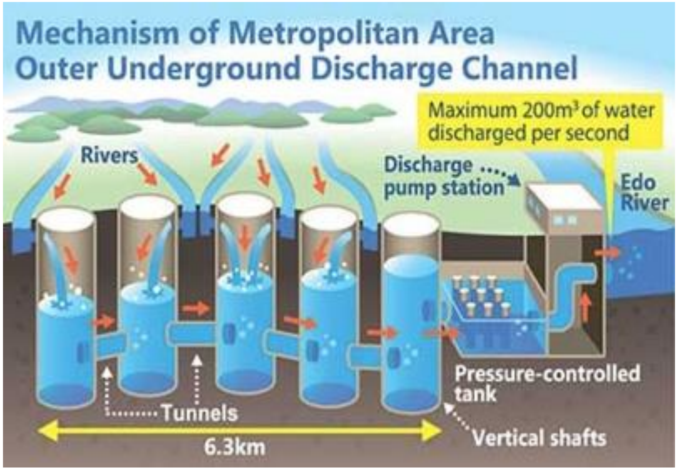

Figure 11: Explanation of how the Metropolitan Area Outer Underground Discharge Channel functions

3.2.2.3 Effectiveness in preventing water disasters

Since the underground river discharge channels first began its operation, it has regulated floods for more than 100 times. The effect that these discharge channels have had on flood control has been remarkable, and the flood damage on the Naka and Ayase River basin (the area called Kasukabe) has been largely mitigated.
When the Naka and Ayase river basin was met with a large typhoon in July 2000, they recorded 160mm of rain and as a result, 137 hectares of land, and 248 buildings faced flood damage. However, after the beginning of its trial water conduction, even though over 200mm of rain was recorded in October 2004, only 73 hectares and 126 houses were met by flood damage, which was a significant improvement [34].
Moreover, soon after the completion of the metropolitan area flood control channel and the start of its full operation, due to the cyclone, the Naka and Ayase river basin recorded over 172mm of rain, yet the flood damage was mitigated to only 33 hectares and 85 buildings, alleviating the damage even further [35]
Furthermore, when Tokyo recorded one of the biggest ever rainfalls in August 2008, due to the operation of this metropolitan area outer underground discharge channel,

approximately 1,172 million cubic meters of water was adjusted, reducing the flood damage significantly. Overall, the flood damage in the Kasukabe area in the past few years has become under a tenth of what it used to be in the 1980s. [36]

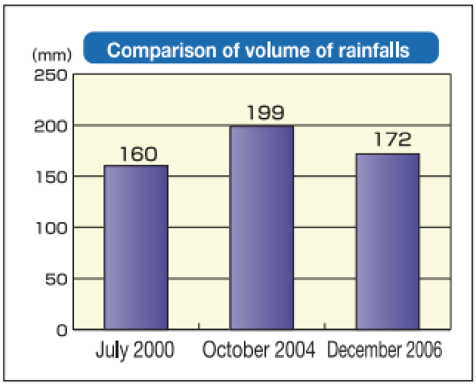

Figure 12: Comparison of the volume of rainfalls

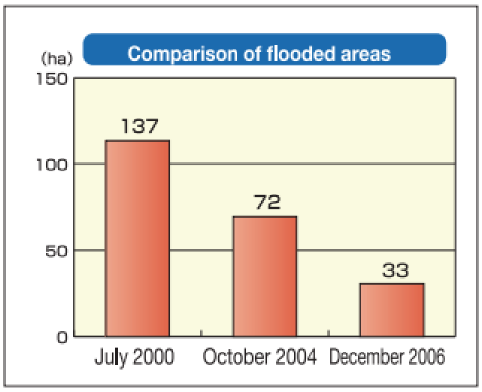

Figure 13: Graph showing the decrease in flooded areas as a result of the Outer Metropolitan Area Underground Discharge Channel

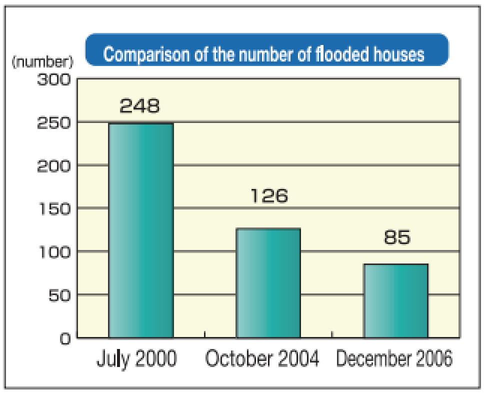

Figure 14: Graph showing the decrease in the number of flooded houses as a result of the Outer Metropolitan Area Underground Discharge Channel

3.2.2.4 Overall effect of the Outer Metropolitan Area Underground Discharge Channel

Kasukabe City, where the Metropolitan Area Outer Undergound Discharge Channel was constructed, is where the bypass of Route 6 and Route 16 intersect, and is ideal as a transportation hub for the Tokyo metropolitan area. However, because the city had always been prone to floods, establishing corporations in the city was considered risky. The city is actively advertising that the construction of the discharge channel has assuaged such fears of corporations and that the city has a sufficient transportation network, ideal living environment, and is also invulnerable against water disasters through pamphlets and the internet in order to attract businesses. As a result, in 2014, 28 companies have established their businesses in Kasukabe City, and the employees of the 28 companies reach more than 3,200 people [39]. Within the 28 companies, there are companies that have constructed large commercial facilities. This has made life for the locals of the city more convenient, has increased job opportunities for locals, and has had a positive impact on the city's finance as well.

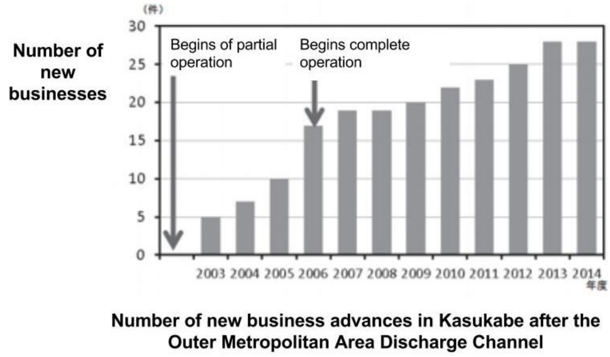

Figure 15: A graph showing the increase in new business advances in the Kasukabe area after the implementation of the Outer Area Metropolitan Discharge Channel

3.3 The necessity for more effective river management systems in metropolises

Flood disasters inflict a great damage upon the society by not only halting the function of the city but also causing social, economic, and environmental damages that can last for decades. Although the extent of the damage can depend on the vulnerability and value of the affected environment, in this chapter, we would like to discuss how much water disasters are affecting our lives yearly and how this situation can be assuaged by the implementation of the underground discharge tunnel.

3.3.1 Social Consequences

Some of the major social effects that water disasters have are the loss of human life, agricultural damage, the spread of water-borne diseases, and the disruption of the supply of clean water. Water disasters, similar to other natural disasters, can traumatize victims, lead to displacement from houses, and poverty. Water-borne diseases are a critical issue in recent years as the concrete roads prevent the water from receding, and the germs spread inside of the contaminated water. [40]

3.3.2 Economic Consequences

Economic damages are another critical issue. Floods greatly affect businesses, and loss of vital human resources as well as land value can leave the society economically vulnerable. Effects on roads, railroads, transport hubs, and shipping ports can have a great impact upon both the regional economy as well as the national economy. Moreover, regions affected by floods may experience a drastic decrease in the number of tourists, and restoring the numbers could take years.

The amount of economic damages varies in countries depending on how much influence the region has upon the nation, as well as the world. Floods are considered one of the most expensive types of natural disasters in many countries, and the Chennai Floods that occurred in India in 2015 was ranked 8th in the most expensive natural disasters of 2015, with a 3 billion dollar loss [41].

Rank	Flood	Economic Damage (in billion U.S. dollars)
1	Thailand, (Aug 5, 2011)	40.0
2	China, (July 1, 1998)	30.0
3	China, (May 29, 2010)	18.0
4	India, (September, 2014)	16.0
5	Korea Dem P Rep, (August 1, 1995)	15.0
6	Germany, (May 28, 2013)	12.9
7	China, (June 30, 1996)	12.6
8	U.S., (June 24, 1993)	12.0
9	Germany, (August 11, 2002)	11.6
10	U.S., (June 9, 2008)	10.0

Figure 14: Ranking of the potential economic damage caused by floods [43]

3.3.3 Environmental consequences

Although less known compared to economic damages, there are indeed environmental damages caused by floods. Hazardous substances can contaminate the floodwaters and pollute the rivers after the waters recede [44]. However, the negative impacts on the environment are mainly caused by humans and not by the water disaster itself because floods are part of a natural cycle.

3.4 River management systems in other major metropolises

3.4.1 London

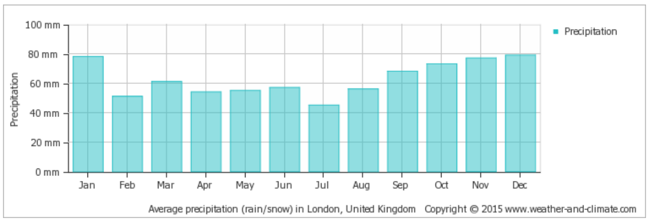

Figure 12: Precipitation levels in London[45]

There has been a rise and fall in London's population after its creation as a Roman city in 43 A.D. It reached a peak of 8.5 million in 1940 but declined during the Second World War. Rapid modernization took place after the Industrial Revolution in the 18th century when it became one of the largest, as well as the most influential city in the world. The current population is 8,539,000 and the population density is 5,491people per square kilometer. [46]
An example of the water management system in London is the Thames Barrier built in 1982, which is a flood barrier that prevents the Thames River from overflowing. The most recent case of its use was in February of 2016 when heavy rainfall resulted in the fluctuation of water levels in the Thames River. Most parts of London are low flatlands and are surrounded by mountains on the outskirts of the city, shaped like a basin. [47]

3.4.2 New York

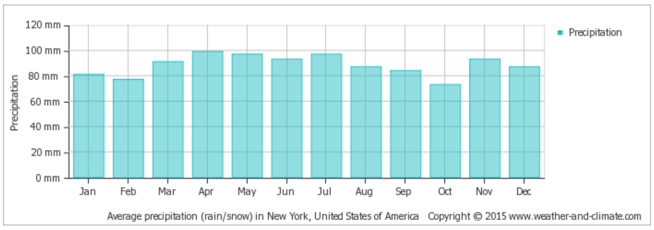

Figure 13: Precipitation levels in New York [48]

New York became the center of politics during the 18th century when it was the capital of the United States. Every since then, it has been a bustling city, and its current population is 8,406,000 with a population density of 2,050 people per square kilometer. [49]
A major issue in New York is that it is vulnerable towards water disasters, and experienced a complete shutdown of the city during floods in January of 2016. Therefore, the city is planning to invest in a 100 billion dollar project to build levees, floodwalls, and parkland. The topographical feature of New York is that it has the Hudson River, which flows into the Atlantic Ocean that leads to scarce availability of land. The city's land has been altered by human intervention, and land reclamation began from the Dutch colonial times. Therefore, although some parts of the city were initially mountainous, humans evened the land, and it can be speculated that this is making it difficult for floodwaters to recede during heavy rainfall.

3.4.3 Seoul

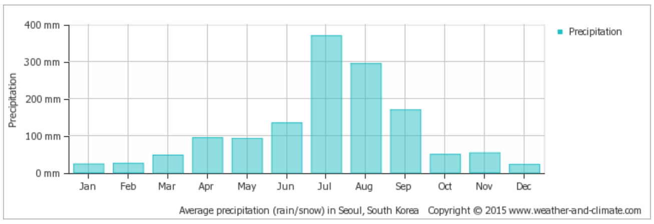

Figure 14 : Precipitation levels in Seoul[50]

Seoul drastically developed after the ceasefire of the Korean War in 1953, and its current population is 10,010,000. Population density is 16,700 people per square kilometer. The topographical feature of Seoul is that the Han River flows through the city from east to west and the city is surrounded by mountains that are 700 to 800 meters high. The Nam Mountain is situated in the center of the city. The city's last experience of a large-scale flood in July of 2015, and after this flood, the municipal government adopted a plan to improve the drainage infrastructure. Currently, Seoul has an underground tunnel that carries excess water in the Han River to Gwanghamun Square. [51]

4. Analysis

4.1 The effect of constant floods on the development of river management systems

As a result of Tokyo being an area so prone to water disasters, Tokyo has been able to gradually develop ways to prevent water disasters from causing damage to its citizens. Through experiencing many water disasters, the government has decided to take action to prevent further damage. What we can learn from Tokyo and Japan's gradual development in water management systems is that it is something that takes time and effort. But that effort is only cultivated by the fear of facing another flood in the future. We think that this is something we should overcome. Rapidly developing cities often may not see the danger of water disasters and the importance of river management until it is too late.

4.2 The effect of river management laws on the effectiveness of river management systems

New river laws which passed in the past few decades, have policies which cover three aspects; the use of river water, the prevention of river floods, the protection of the environment. With the river laws covering up these three aspects, the people are able to use, and live around the water safely with reassurance. In addition, the river law we have today, makes the river manager to continue to make improvements. In addition, by categorizing the rivers by their importance and changing the river manager according to the river's category helped efficient improvements to be made on important rivers. Since the MLIT manages the important rivers, there are more money that can be spent on the important rivers. This allows better and larger scale improvements to be made for the rivers. One result of this is the Outer Metropolitan Area Underground Discharge Channel. Furthermore, because disasters hinder industrial development, drastic economic growth can be seen during periods with few disasters. These facts highlight the importance and benefits of the construction of water management systems for both the citizens and the politicians, although its significance tend to be overlooked.

4.3 The success of the Outer Metropolitan Area Underground Discharge Channel

The execution of the construction of the Metropolitan Area Outer Underground Discharge Channel is an ideal example of successful leadership and policy-making. As it can be seen in the graphs below, despite the fact that the amount of rainfall has not changed drastically over the years, the amount of flooded areas and houses have declined. Because the discharge channel began partially conducting in 202, the data reveals how much of a difference the system has made after its construction. Moreover, according to studies, during heavy rainfall (more than 100mm in 48 hours), 84,014 houses experienced floods in the 1980~1989. On the other hand, during the 2000~2010, only 5,745 houses experienced floods, 1/10 of the previous statistics. Also from 2002 to 2014, the channel was able to prevent floods that were expected to lead to losses of approximately 48.1 million yen. During the floods in October of 2004 and August 2008, the system was able to prevent the loss of 5.3 million yen and 10.7 million yen by using the discharge channel. Considering that the construction of the system cost 227.1 million yen and keeping in mind that the system will continue to be used for floods; the project can be seen as a meaningful investment [52]

4.4 Differences in river management between metropolises

Through research, we have come to the conclusion that despite the fact that all three metropolises have different features according to the environment, there are similarities in water management systems. The factors causing these similarities can be speculated as history, demography, and topography. History has been a cause of resemblances because cities with long history tend to have water management systems above ground while cities that drastically urbanized in recent years have facilities underground. Although this may be due to the development of technology in constructing infrastructure, it can also be thought that it is because cities with history have carefully planned the course of the city's development. Because many people have lived in the city for centuries, they have been able to thoroughly research about the region's climate and therefore have built water management systems before many other regions. London and New York are such examples. On the other hand, both Seoul and Tokyo experienced rapid development after the Korean War and the Second World War. Therefore, water management systems tended to be neglected during the city planning, and the water management systems were installed years after the city began accommodating more people. Another triggering factor is demography. Based on the population and the population density, it can be indicated that population density is a crucial factor when contemplating water management systems. If the amount of land is scarce, large-scale water management systems cannot be constructed within the city. All water management systems that were introduced are suitable for metropolises because they are either small-scaled or underground. Also, topography is a crucial factor for the construction of water management systems because it reveals why the systems was initially necessary. New York, Seoul, and Tokyo share similarities because all of the cities are basin-like and vulnerable towards rain flowing rapidly from the mountainside to the city. To conclude, metropolises have developed their original water management systems but they have all be constructed based on the same needs and backgrounds. Moreover, resemblances can be seen in where the systems are situated and how it functions because of similar environmental factors.

4.4 Drawbacks for the successful implementation of Tokyo's river management system abroad

4.4.1 High financial cost

The Outer Metropolitan Area Underground Discharge Channels cost the Tokyo Metropolitan government 227 billion 100 million yen (approximately 1,900 million U.S dollars). Governments must have the ability to pay this large sum.

4.4.2 Geographical Requirements

The underground water palaces must be surrounded by large rivers to release excess floodwater. In Tokyo, the

Edogawa river serves this purpose. Therefore, cities where large rivers have gone though land reclamation for construction of infrastructures will not be able to incorporate the underground water palaces. Moreover, the large rivers must flow rapidly as well, in order to allow the floodwaters to be released into the ocean. Therefore large rivers that flow through mountainous regions will be more suitable for the project.

4.4.3 High-level technology

Tokyo was the first city in Japan, as well as the world, to have developed underground palaces by applying technology used on airplanes. Therefore, when exporting technology for preventing water disasters, it is crucial for Japan to share its technology with other nations. Moreover after visiting the water palace, we heard from the employee that the maintenance of the facility is difficult, and the water palace requires cleaning once a year using a large crane and bulldozer. The bulldozer needs to be carried 18 meters into the ground using a crane, and the soil from the contaminated water that travels through the underground palaces must be brought back to the land. The soil, then, is carried to nearby rivers to be reused as riverbeds. Cities willing to adopt Tokyo's technology must be capable of carrying out this laborious work safely and quickly.

5. Proposals

5.1 Introduction of River laws to enforce proper management of rivers

Since every country has different geographical features, the river law should differ according to its country. However, there are aspects of Japan's river law, which can be adopted in other places, and could possibly help in making river managing improvements. We would like to introduce those aspects that has also helped Japan to become as it is today. As mentioned above, Japan's river law has helped the improvements made for rivers. It is mandatory for the river offices to make specific and long term plans for improvements on the environment, prevention of river floods, and use of river water. This has resulted a comprehensive evolution in the river management. The introduction of mandatory plans would help areas to continue improving even after adopting parts of Tokyo's river management system. In addition to this, one of Japan's river law's features; categorizing rivers according to its importance and changing the river manager with each category, can also be introduced to other countries. In Japan, the important rivers are managed by the MLIT and therefore the government can spend more money on the important rivers. This system would help the important rivers to be managed efficiently.

5.2 Implementation of underground river discharge channels

5.2.1 Careful Consideration of Costs and Benefits

From the example of Tokyo's Outer Metropolitan Area Underground Discharge Channel, we can understand that river discharge channels are very costly. Nearly 2000 billion dollars (the amount of money it took to build the Outer Metropolitan Area Underground Discharge Channels") is not the amount of money that countries can dispose of easily. Therefore, it is very easy for governments to be blinded by the short term large cost of constructing the large scale river management systems. However, from the example of Tokyo's "Outer Metropolitan Area Underground Discharge Channels" we can see that these discharge channels are very effective, and is a good investment considering the amount of damages that they prevent. Even if we disregard the economic benefit, the fact that the government can prevent the wrecked lifestyles and loss of lives, is in itself an important achievement that the government should strive to achieve. Thus, governments should consider the costs and the benefits of building underground river discharge channels in a long-term perspective.

5.2.2 Exportation of Japan's technology

The Japanese government as well as companies in Japan has continuously showed its willingness to export its technology to other countries. The expenditures for the exportation of technology reached a record high in 2012, and is continuing to increase, according to a research conducted by the Ministry of Internal Affairs. Currently, there are no plans for the exportation of the technology for underground water palaces, but speculating from the benefits that this water management system has brought to Tokyo, the exportation of this technology is something that the Japanese government should actively pursue. Tokyo has one of the most developed river management system, with technologies that they have gained through hard work and expertise. They should use this to their advantage to strengthen ties between countries by exporting this technology, and helping many people around the world living in areas which are prone to floods.

5.2.3 Consideration of Geographical appropriateness

Whether the metropolis is geographically appropriate for the implementation of large underground discharge channels is a very important factor which must be considered. As we have seen from the comparison of Tokyo's river management system with other metropolises, each city must use the different tools to suit its own needs. In the case of underground river discharge channels, the geographical requirement for a successful implementation is that it has a large, rapidly flowing river to release the excess water. As many metropolises are built around rivers, many do meet this requirement, so it is not something that is very exclusive. But governments should carefully consider whether the underground discharge channel is the best system for them.

6. Conclusion

Through this essay, we have described the development and the current state of river management system in Tokyo, and proposed the idea of exporting the technology and the managing methods. Tokyo's underground discharge channels can be said to be the fruit of Japan's technology. These channels can help areas to industrialize and assure safety for the citizens. Therefore, Japan's river management will not stop here, and will continue to develop new ways to assure comfort for the citizens. However, not only do we want Japan's river management to continue improving, we also want Japan's river management system to be known throughout the world. The geography would change in different areas, however there are aspects of Japan's river management system that many areas can adopt. We wish that our proposal would help other areas to consider and learn from Tokyo's river management system.

Acknowledgements

We would like to thank our teachers, Ms Natsume, and Ms Ishihara for their time and profound support throughout the whole process of deciding the members, making sure we understood what we were doing, helping us to find out what we wanted to write about, and guiding us throughout this whole process. We would not have been able to complete this report or take part in the conference without them. We would also like to thank Mr. Parker for choosing us to take on this project, and also Mr. Nancoo for taking his time to look over our paper to help us

References

[1] "Physical Panoramic Map of Kanto." Maphill. 28 March 2016. <http://www.maphill.com/japan/kanto/panoramic-maps/physical-map/>

[2]"Average Monthly Snow and Rainfall in Tokyo." World Weather & Climate Information. 31 March 2016. <https://weather-and-climate.com/average-monthly-precipitation-Rainfall,Tokyo,Japan>

[3,4,5,7] "A country prone to floods" Ministry of Land, Infrastructure, Transport, and Tourism. 22 March 2016. <http://www.mlit.go.jp/river/pamphlet_jirei/bousai/saigai/kiroku/suigai/suigai_3-1-1.html>

[6] "Typhoon statistics" Japan Meteorological Agency. 22 March 2016. <http://www.data.jma.go.jp/fcd/yoho/typhoon/statistics/index.html>

[7,10] "River management and Utilization" Tokyo Bureau of Construction. 21 March 2016. <http://www.kensetsu.metro.tokyo.jp/english/kasen/gaiyo/02.html>

[8,9] "Things you didn't know about your country" Japan Institute of Country-ology and Engineering. 21 March 2016. <http://www.jice.or.jp/knowledge/japan/commentary08>

[11,12,13,14] "The current situation of rivers and its problems." Ministry of Land, Infrastructure, Transport, and Tourism. 22 March 2016<http://www.mlit.go.jp/river/pamphlet_jirei/kasen/gaiyou/panf/gaiyou2003/pdf/1.pdf>

[15,23] "How disasters occur" National Research Institute for Earth Science and Disaster Prevention.<http://dil.bosai.go.jp/workshop/02kouza_jirei/s01kanto/tonekouzui.htm>

[16,18] Sundermann, Lukas, et al. (2014) *Mind the risk - a global ranking of cities under threat of natural disasters.* Swiss Re. March 25th 2016. <http://media.swissre.com/documents/Swiss_Re_Mind_the_risk.pdf>

[17,19] Takeshi, Mizutani. "Japan's cities and other major cities' natural disaser risk comparison" March 17th 2016. <http://members3.jcom.home.ne.jp/mizut/column/risk/riskindex.html>

[20,21]Shigeki, Matsuura. "The Meiji era's major water disaster and long term primary flood control systems" Toyo University. March 2008. 24 March, 2016. <http://rdarc.rds.toyo.ac.jp/webdav/frds/public/kiyou/0708/tiiki/0803/matsuura.pdf>

[22] "The terrible high tide water disaster" Chiba Prefecture Homepage. 30 March 2016.< <http://www.pref.chiba.lg.jp/bousai/bousaishi/documents/dai2syou_3.pdf>

[24] "The great flooding of the Tone River" The Tone River Management Office. 21 March 2016. <http://www.ktr.mlit.go.jp/ktr_content/content/000109235.pdf>

[25] "The Tokyo Lowlands –the most dangerous, disaster prone place on Earth" Ministry of Land, Infrastructure, Transport, and Tourism. 24 March 2016. <http://members3.jcom.home.ne.jp/mizut/kouza/area/01tokyo/tokyoteichi.html>

[26]"The Nightmare-like experience of the Tamagawa Floods" Komae City. 30 Jan 2006. 24 March 2016. <https://www.city.komae.tokyo.jp/index.cfm/45,336,349,2102,html>

[27,30] "River laws" National Institute for Land and Infrastructure Management. 2004. 25 March 2016. <http://www.nilim.go.jp/lab/rcg/newhp/yougo/words/104/104.html>

[28] "History of our country's river management system" Ministry of Land, Infrastructure, Transport, and Tourism. 25 March 2016. < http://www.mlit.go.jp/river/shinngikai_blog/past_shinngikai/shinngikai/shingi/to9612-1.html>

[29,31] "Construction work's basic plan and river maintenance basic policies and its Relationship with river maintenance plans" Wakayama River Management Committee. 1 April 2016. < https://www.kkr.mlit.go.jp/wakayama/ryuiki_iinkai/ryuiki/study/pdf/2.pdf>

[32] "Management of Rivers and its use" Tokyo Bureau of Construction. 29 March 2016. < http://www.ktr.mlit.go.jp/edogawa/gaikaku/intro/04kouka/index.html>

[33,34,35,36,37,38] "The Metropolitan Area Outer Underground Discharge Channel." *Ministry of Land, Infrastructure, and Transportation*. 2014. 31 March 2016. <http://www.ktr.mlit.go.jp/ktr_content/content/000106826.pdf>

[37]"Flood Control Economic Survey Manual" Ministry of Land, Infrastructure, and Transportation, River management office. 28 March 2016. http://www.ktr.mlit.go.jp/ktr_content/content/000053312.pdf

[39] Kazunari, Ishida. "Infrastructure Stock effect of the Outer Metropolitan Area Underground Discharge Channel" September, 2015. 1 April, 2016.

<http://www.ejcm.or.jp/new_07ronbun/monthly/1509/PDF/1509-03.pdf>
[40] "What are the consequences of floods?" Queensland Government. 2 April 2016. <http://www.chiefscientist.qld.gov.au/publications/understanding-floods/flood-consequences>
[41] Narasimhan, T E. "Chennai floods are world's 8th most expensive disaster in 2015". 11 December, 2015. 30 April 2016. <http://www.business-standard.com/article/current-affairs/chennai-floods-are-world-s-8th-most-expensive-natural-disaster-in-2015-115121100487_1.html>
[42] "The 100 Most Expensive Natural Disasters of the 20TH Century" The Disaster Center. 28 March 2016. <http://www.disastercenter.com/disaster/TOP100C.html>
[43] "The Most Catastrophic Floods in the World and their impact". World Atlas. 16 October 2015. 25 March 2016. <http://www.worldatlas.com/articles/the-most-catastrophic-floods-in-the-world-and-their-costly-impact.html>
[44] "Effects of Flooding" eSchoolToday..<http://eschooltoday.com/natural-disasters/floods/effects-of-flooding.html>
[45] "London, United Kingdom" World Weather and Climate Information. 20 March 2016. <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,London,United-Kingdom>
[46] Smith, Duncan. "London's metropolis high: top metropolis facts". 2 February 2015. 15 March 2016. <http://www.bbc.com/news/uk-england-london-31056626>
[47] "London" Topographicmap.com. 16 March 2016. <http://en-gb.topographic-map.com/places/London-92172/>
[48]"New York, United States of America" World Weather and Climate Information. 21 March 2016. <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,New-York,United-States-of-America>
[49] "New York City's Population Peak". March 17, 2001. 20 March, 2016. <http://www.nytimes.com/2001/03/17/opinion/new-york-city-s-population-peak.html >
[50] "Seoul, South Korea" World Weather and Climate Information. 20 March 2016. <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Seoul,South-Korea>
[51] "Seoul's Lessons for Asian Urban Flooding." Asia Sentinal. 14 August 2012. Web. 31 March 2016. <http://www.asiasentinel.com/society/seouls-lessons-for-asian-urban-flooding/>
[52] "The Metropolitan Area Outer Underground Discharge Channel." *Ministry of Land, Infrastructure, and Transportation*. N,p. 2014. Web. 31 March 2016. <http://www.ktr.mlit.go.jp/ktr_content/content/000106826.pdf>

Japan International Cooperation Agency 『調査研究「防災と開発」報告書～社会の防災力の向上を目指して～』(2003)<http://jica-ri.jica.go.jp/IFIC_and_JBICI-Studies/jica-ri/publication/archives/jica/field/pdf/2003_03e.pdf>

Tokyo Geology Investigation Organization 東京都地質調査業協会「技術ノート」(2006) <http://www.tokyo-geo.or.jp/tech-note-pdf/No39_1.pdf>

Yamazaki, Noboru 山崎登 『歴史に学ぶ洪水対策』(2014)<http://www.nhk.or.jp/kaisetsu-blog/700/191680.html>

河川部計画課計画調査係「過去の水害記録」<http://www.kensetsu.metro.tokyo.jp/suigai_kiroku/kako.html>