Flood control in small urban rivers: an example of river projects in Tokyo

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Abstract

The Tokyo Metropolitan Government (TMG) has conducted a variety of river projects to protect citizens and their property from damage due to flooding, storm surges, and landslides. Projects have also been undertaken to improve and create riversides that support nature, and to protect and restore the natural environment. The hardening of urban and inner city areas with high population densities and developed areas have relatively poor water retention and flood prevention properties. Consequently, these areas have sustained extensive water damage during times of heavy rainfall and flooding. Indeed, extensive flood damage was observed in downtown areas as recently as September 2005 and August 2008, demonstrating the need to implement additional flood mitigation measures to prevent flood damage in the metropolitan area. The number of rivers currently under the direct management of the TMG is 61 class A rivers and two class B rivers, which together measure 494.82 km. In addition, the city office of the TMG also controls 33 class A rivers and 13 class B rivers, which together equal 215.91 km. The main projects undertaken by the TMG is small river development, reinforce of lowland, improvement of the river environment for ecology, improvement of sediment disaster control facilities, development of software programs, river enlightenment activities and improved shoreline protection measures. In 2010, the total costs of river projects amounted to approximately JPY 65 billion. Small river projects are primarily concerned with the construction of several regulation reservoirs and river diversion channels. Conversely, the development of high tide breakwater structures and the reinforcement of rivers in lowland areas using super levees

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are important large-scale projects. Recently, special emphasis has been placed on earthquake measures, such as disaster prevention piers or water gates. In this paper, we describe flood control measures of small rivers in the Tokyo metropolitan area, with particular emphasis on regulating reservoirs.
Keywords: flood control, small rivers, regulating reservoir, disaster prevention.

1 Introduction

Recently, extensive flood damage due to heavy rainfall, tsunamis or the failure of levees has been reported around the world. In many cases, abnormal weather and extensive deforestation associated with urban development has been responsible for this extensive damage. In many cases, the severity of these floods has primarily been due to a lack of flood plain management. River improvement measures have numerous functions, most of which are related to ensuring the safety of civilian lives and property from flood damage, securing the water resources that support a rich lifestyle, protecting areas from erosion damage and landslides, ensuring safety and serenity along coastal areas, maintaining the information networks that protect lives, preventing disasters, and creating pleasant water environments. In order to achieve these aims, it is necessary to improve river channels by constructing floodways, detention basins, flood control basins, water reservoirs, underground discharge channels, storm water systems, etc.

River information systems are also important for protecting lives. The TMG has conducted a variety of river projects to protect citizens and their property from water damage, such as that caused by floods or storm surges and landslides, and also to create riversides environments that are rich in nature, and to protect the natural environment.

The Tokyo Metropolitan Area, which has primarily expanded along an east-west axis, is bounded in the west by the Okuchichibu Mountains with a central plateau referred to as the Musashino Plateau and eastern lowlands bordering Tokyo Bay. Tokyo's rivers generally flow westward into Tokyo Bay.

Figures 1 and 2 show the main islands of the Japanese archipelago and the Tokyo metropolis, respectively. Tokyo is drained by five major river systems/consists of five major river catchments; the Tama River system that flows eastward and empties into Tokyo Bay, the Tsurumi River system that runs through the southern region of the Tama Hills, the Arakawa River system runs through the Musashino Plateau, the Tone River system runs from north to south in the eastern lowlands, and the other river systems run directly into the sea.

A total of 107 rivers with a total length of approximately 858 km drain the Tokyo metropolis region. Of these, the TMG manages about 711 km of 105 rivers; 46 of these rivers are managed by Tokyo Special Ward Governments and about 33 km of 20 small rivers (locally designated rivers) are managed by municipalities [1, 2].

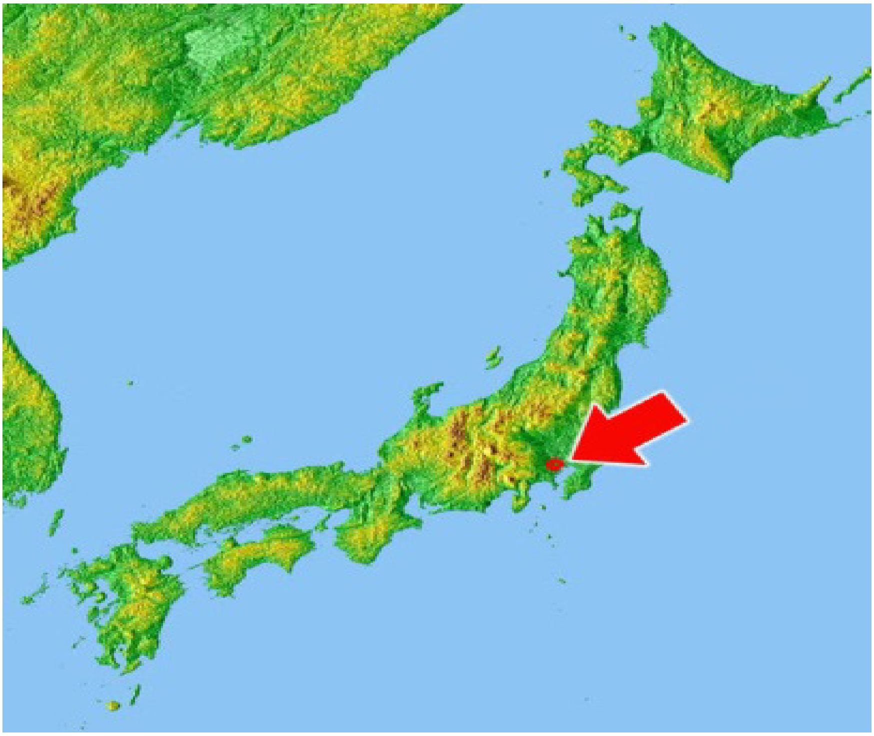

Figure 1: The main islands of the Japanese archipelago.

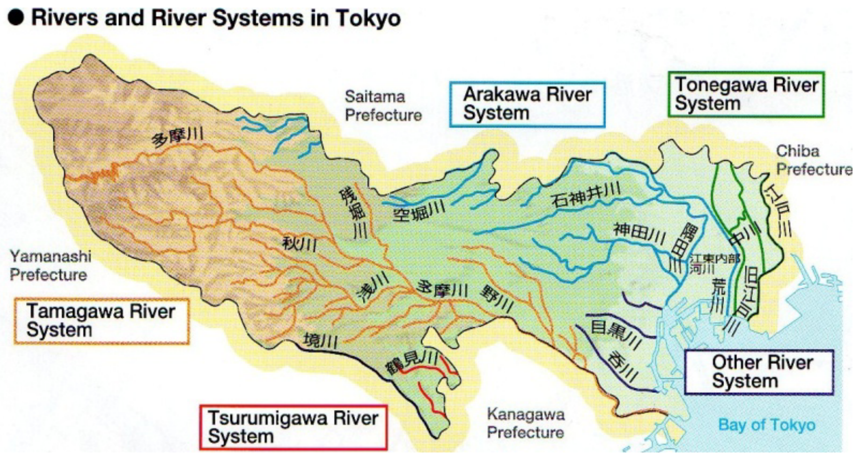

Figure 2: The Tokyo metropolitan area.

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2 Flood hazards in Tokyo

Dates on which extensive damage to properties in the Tokyo metropolitan area occurred are shown in Table 1 [3, 4].

Table 1: Characteristics of floods and associated damage in Tokyo.

Year	Frequency (events/year)	Affected area (ha)	Above ground (houses)	Below ground (houses)
1975	12	748.1	7,676	403
1976	5	385.0	6,145	2,190
1977	12	126.7	2,677	214
1978	2	284.2	5,353	2,338
1979	9	322.9	4,426	1,352
1980	2	12.3	266	5
1981	4	2,429.4	45,780	9,982
1982	7	2,539.0	25,121	9,038
1983	5	786.6	8,732	447
1984	2	18.1	164	8
1985	6	322.1	9,344	1,645
1986	7	46.1	5,851	838
1987	7	183.7	6,765	1,056
1988	5	7.88	421	46
1989	6	93.46	3,312	2,187
1990	7	37.40	963	110
1991	10	190.60	3,315	613
1992	4	21.97	427	106
1993	6	390.32	5,802	2,867
1994	7	15.35	556	85
1995	4	4.23	152	68
1996	2	5.52	64	16
1997	9	27.99	193	135
1998	6	9.27	320	236
1999	9	180.06	2,932	3,648
2000	9	20.63	748	264
2001	7	16.74	314	198
2002	9	14.42	453	518
2003	8	11.16	322	164
2004	5	43.62	1,041	955
2005	8	180.43	2,660	3,576
2006	5	1.97	82	44
2007	6	10.75	127	57
2008	7	20.56	323	307
2009	5	10.77	225	163

Table 2 shows the highest values recorded for maximum hourly rainfall and Table 3 shows the maximum daily rainfall for the Tokyo metropolitan area. These records values were recorded by the Tokyo District Meteorological Observatory before 2009 [3, 4].

Table 2: Largest maximum hourly rainfall values in Tokyo.

Ranking	Date	Amount of rainfall (mm/hr)	Weather conditions
1	August 29, 1999	115.0	-
2	September 4, 2005	112.0	-
3	July 31, 1939	88.7	-
4	July 4, 2000	82.5	Torrential Downpour
5	July 22, 1981	80.0	-

Table 3: Largest maximum daily rainfall values in Tokyo.

Ranking	Date	Amount of rainfall (mm/hr)	Weather conditions
1	September 22-27, 1958	444.1	Typhoon
2	August 26-28, 1993	345.0	Typhoon
3	September 11-12	313.0	Typhoon
4.	August 7-11, 1910	283.9	Storm
5	June 29, 1938	278.3	

The most severe typhoons to hit the Tokyo metropolitan area were as follows. Typhoon Kathleen hit the Kanto area on September 15, 1947 resulting in the collapse of the Tone River levee in the upper reaches on September 16, 1947. As a result, the muddy stream entered the Tokyo metropolitan area after several days, causing extensive sedimentation of the urban areas downstream/old flood plain. The maximum hourly rainfall was 34.7 mm/hour, the total amount of rainfall 166.8 mm (September 13–15), the area inundated was 114.32 km^2, with above- and below-ground damage caused to 80,041 and 45,167 houses, respectively, and 11 fatalities [5].

Typhoon Kitty occurred, the abnormal Takashio (Storm Surge) due to the typhoon occurring at high tide in Tokyo Bay. As a result, extensive flooding occurred in the low-lying downtown regions of the Tokyo metropolitan area on September 1, 1949. The maximum hourly rainfall was 12.6 mm/hr, the total rainfall was 64.9 mm (August 31 - September 1), 92.01 km^2 was inundated, with above- and belowground damage caused to 73,751 and 64,127 houses, respectively, and 122 fatalities [5].

Typhoon Kanogawa (Ida) caused a torrential downpour on September 26, 1958 since the meteorological observation in Japan started. Serious damage occurred along small rivers in the Tokyo Metropolitan area. The maximum hourly rainfall was 76.0 mm/hr, total rainfall was 392.5 mm (September 22–27), the area inundated was 211.03 km^2, with above- and belowground damage caused to 123,000 and 340,404 houses, respectively, and 203 fatalities [5].

3 Flood control

Small river improvement projects have been undertaken to prevent damage due to flooding in the smaller rivers on areas of the plateau in central Tokyo. The projects typically involve construction or improvement of revetments, retention basins, regulating reservoirs and diversion channels. This has been necessary because urban and inner-city areas with high population densities and developed properties have experienced have lower water retention and flood prevention capacities. Consequently, it is these areas that have sustained extensive water damage during times of heavy rainfall. For example, the extensive flooding associated with the relatively recent downpours of September 2005 and August 2008 illustrated the need for further river development measures to prevent inundation of the metropolitan area.

Of the small rivers managed by the TMG, river improvement projects have been undertaken by the TMG so that these rivers can handle a rainfall intensity of 50 mm/hr. In areas where early river improvement is difficult, retention reservoirs have been built to store at least some of the floodwaters. As of 2011, approximately 209.8 km (65%) of the small rivers under TMG management have been improved in the Tokyo metropolitan area. In addition, 34 regulating reservoirs and 9 diversion channels are planned in the future. 23 regulating reservoirs and 7 diversion channels were finished in 2010, and 4 regulating reservoirs and 1 diversion channel were constructed in 2011. Moreover, 8 regulating reservoirs and 1 diversion channel will be constructed shortly. Tables 4(a) ~ 4(c) shows the regulating reservoirs and Table 5 shows the diversion channels in Tokyo [6].

The Kanda River/ Loop Road No.7 Underground Regulating Reservoir is a 4.5 km long underground tunnel with an inner diameter measuring 12.5 m, built beneath Loop Road No.7. The tunnel can store approximately 540,000m^3 of flood water from the Kanda River and the Zenpukuji River to improve safety control of floods that often occur in the middle of the Kanda River.

The regulating reservoir, which was completed in March 2008, is capable of effectively storing water from each river under a variety of rainfall conditions, and has been very effective in reducing water damage in the Kanda River basin. The Kanda River basin had a mean hourly rainfall of about 50 mm and a total rainfall of about 150 mm, which rapidly raised the water level in the river. However, the regulating reservoir constructed under Loop Road No.7 is capable of storing flood waters to its 94% of the total capacity, or about 505,000 m^3, the largest volume ever received by this tunnel type reservoir, to successfully prevent flood damage. Figure 3 is the Kanda River Loop Road No.7 Underground Regulating Reservoir. The length and the drainage area of the Kanda River are 24.6 km and 105 km^2, and the length and the drainage area of the Zenpukuji River are 10.5 km and 18.3 km^2. The Ebara regulating reservoir

Table 4(a): Completed regulating reservoirs in Tokyo.

River name	Site name	Site area (m^2)	Storage capacity (m^3)	Year completed
Shakujii	Fujimiike	21,000	33,800	2007
Shakujii	Shibakubo	10,000	11,000	1980
Shakujii	Minamimachi	8,000	12,000	1980
Shakujii	Mukoudai	30,000	81,000	1980
Zenpukuji	Wadabori No.2	5,100	2,500	1978
Zenpukuji	Wadabori No.3	3,900	3,000	1978
Zenpukuji	Wadabori No.6	15,400	48,000	2007
Nogawa	Nogawa No.1	14,800	21,000	1980
Nogawa	Nogawa No.2	16,900	28,000	1989
Nogawa	Ohsawa	43,100	90,000	2001
Shirako	Bikunibashi Upstream	22,000	34,400	1985
Shirako	Bikunibashi Downstream	15,400	212,000	2002
Myoshouji	Myoshouji No.1	11,000	30,000	1986
Myoshouji	Kitaekoda	15,600	17,000	1986
Myoshouji	Ochiai	9,600	50,000	1995
Myoshouji	Myoshouji No.2	11,300	100,000	1995
Myoshouji	Kamitakada	16,600	160,000	1997
Kanda	LoopNo.7 (Underground)		540,000	2007
Zanbori	National Park (Showa)	22,800	60,000	1987
Meguro	Funairiba	2,900	55,000	1990
Meguro	Ebara	11,400	200,000	2001
Yanase	Kanayama	31,500	46,000	2006
Kasumi	Kasumigawa	13,300	88,000	2006
Total			1,922,700	

Table 4(b): Regulating reservoir under construction in 2011.

River name	Site name	Site area (m^2)	Storage capacity (m^3)	Year scheduled for completion
Furukawa	Furukawa		135,000	2015
Kurome	Kuromebashi	14,000	221,000	Use of a part
Shirako	Shirakogawa		212,000	2017
Myoshouji	Saginomiya	10,000	35,000	2012
Total			603,000	

Table 4(c): Planned regulating reservoirs.

River name	Site name	Site area (m^2)	Storage capacity (m^3)
Shirako	Oizumiinokashira		28,600
Shirako	Bikuni Midstream		11,700
Zenpukuji	Wadabori Park		17,500
Zenpukuji	Zenpukuji		35,000
Myoshouji	Nishiochiai	11,200	100,000
Ochiai	Fudobashi	11,000	7,300
Ochiai	Shitayabashi	12,000	9,500
Zanbori	Zanborigawa	50,000	60,000
Total			269,000

Table 5: Existing and proposed diversion channels in Tokyo.

River name	Site name	Length (m)	Section (m)	Discharge (m^3/s)	Year completed
Kanda	Edogawabashi	1,640	2□-7.2x7.5 Double	230	1977
Kanda	Takadanobaba	1,460	2□-6.6x6.65 Double	330	1982
Kanda	Suidoubashi (1)	680	1□-7.2x7.5 Single	125	1971
Kanda	S Suidoubashi (2)	960	1□-7.7x7.45 1□-9.5x7.45 Double	270	1986
Kanda	Ochanomizu	1,300	1ϕ-8.8 Single 1□-6.8x8.0~6.45	80	2000
Shakujii	Asukayama	250	2ϕ-6.5 Double	480	1982
Sen	Koganei	1,900	1ϕ-2.8 Single	20	1978
Misawa	Misawakawa	2,670	1ϕ-5.3~8.1 Horse shoe-shaped	107	1983
Iruma	Irumagawa	1,230	1ϕ-2.2 Single 1□-2.0x2.0	10	2013
Yazawa	Yazawagawa	-	-	-	-

was constructed near a busy shopping area in downtown Tokyo along the Meguro River in 1991-2001 because this area is low lying and frequently damaged by heavy rainfall and occasionally by typhoons. The Ebara regulating reservoir was designed to handle a maximum flow rate of $6m^3/s$ and has a water storage capacity of 200,000 m^3. The reservoir is 30.5 m deep and has an area of 8,970 m^2 and is designed for the rainfall intensity 50 mm/hr. The length and the drainage area of the Meguro River are 7.82 km and 45.8 km^2. Figures 3 shows the Kanda River Loop Road No.7 underground regulating reservoir and Figure 4 shows the Meguro River Ebara regulating reservoir [7–9].

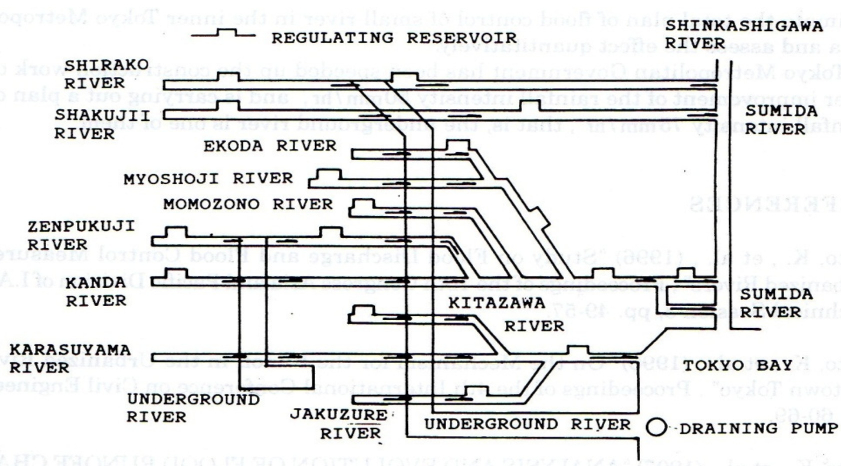

Figure 3: Kanda River loop road No.7 (underground river).

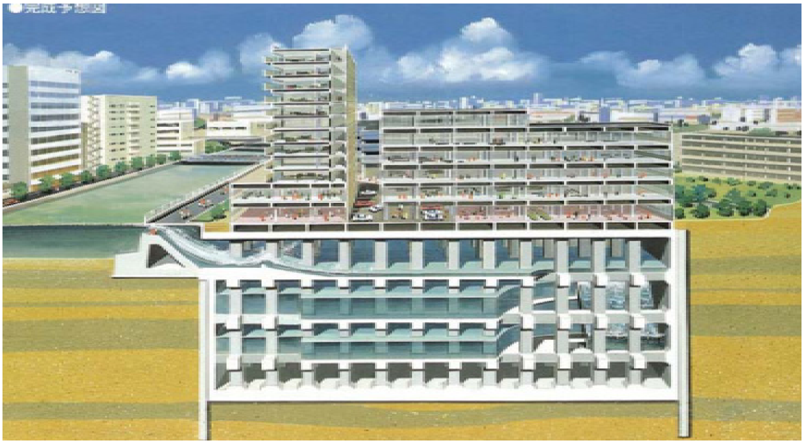

Figure 4: Meguro River: Ebara regulating reservoir.

The basic response/mitigation measures for use against heavy rain in Tokyo were decided in 2007. Since then, the TMG has advanced the need for/has been involved in river improvements, improved sewers, basin measures, and integration of town planning within a regional setting. The five most important small rivers used for predicting flood hazards in Tokyo were identified by the Tokyo Metropolitan Council of Integrated Flood Control. One of these rivers is the Shirako River. Figure 5 shows an image of the regulating reservoirs constructed upstream and downstream of Bikunibashi along the Shirako River. Figure 7 show a tennis court on regulation reservoir of Bikunibashi. The Shirako River in the north of the Tokyo Metropolitan area has a length of 10 km and a drainage area of 25 km^2. A group of regulating reservoirs (storage capacity 34,400 m^3) is used as part of a tennis court and playground complex, as shown in Figure 6.

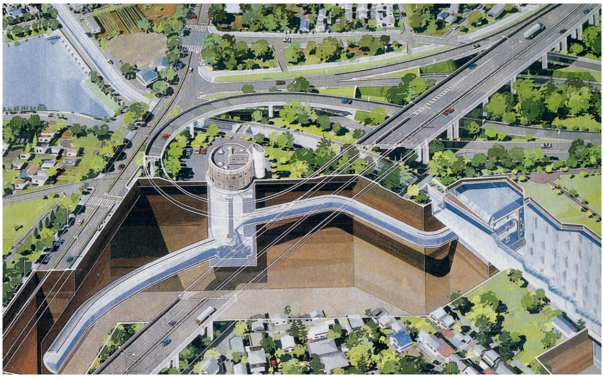

Figure 5: A group of regulating reservoirs along the Shirako River.

Figure 6: Tennis court on regulating reservoir.

Part of the regulating reservoir further downstream is also used as a park (15,700 m^2) and the regulating reservoir has a storage capacity of 212,000 m^3. The inside diameter and length of the underground regulating reservoir is 10.0 m and 3.2 km, respectively, the slope is 1/1,500. The regulating reservoir is about 35 m below the ground surface and has a storage capacity of 212,000 m^3 [10].

The Furukawa River underground regulating reservoir was also constructed by the TMG. The Furukawa River is a small urban river with a length of 4.4 km and a river basin of 8.8 km^2 that flows into Tokyo Bay. Numerous buildings and houses line river and a highway passes above the river. Flood damage occurred along the Furukawa River in 2004, causing social unrest among the local inhabitants. As part of the improvements to the river, the TMG designed an underground regulating reservoir in 2008, and this is currently being built. The underground regulating reservoir, which has an internal diameter of 7.5 m and a length of 3.3 m, is being dug under the Furukawa River. It is being designed to detain 135,000 m^3 [11].

The Myoshouji River which is the upstream of the Kanda River flooded frequently in the past. Although the Myoshouji River is a relatively short river, with a length of at 9.7 km and a basin area of 21.4 km^2, the Kanda River in the lower reaches of the Myoshouji River has frequently been influenced by rising water levels when there is heavy rain upstream, such as when the Myoshouji River catchment was flooded during heavy rainfall (112 mm/hr) in 2005. During that event, 895 and 522 houses were inundated above and below ground, respectively. The Saginomiya regulating reservoir is thus currently under construction. The storage capacity of the Saginomiya regulating reservoir is approximately 35,000 m^3; as in some of the other regulating reservoirs in the Tokyo metropolitan region, part of the reservoir will be used as a playing field. The total area of the system is approximately 30,000 m^2 with the upper level of the regulating reservoir divided into three open spaces, a rest station and a playing field [12, 13].

4 Conclusions

The Tokyo Metropolitan area frequently encounters heavy rainfall exceeding 100 mm/hour, particularly as temperatures have increased in recent years. However, many of the existing river improvement schemes implemented by the TMG are only capable of handling a rainfall intensity of 50 mm/hr. The Tokyo Metropolitan Area is oriented along an east–west axis, extending westward to the a mountainous area approximately 1000 to 2000 m above sea level. Many of the small rivers in Tokyo have their origins in these mountains and then flow downward, across the Kanto floodplain and into Tokyo Bay. It is on this floodplain that many of the rivers improvement schemes are under way as these areas are prone to flood damage, particularly in the central part of Tokyo. Most of the projects conducted to date have consisted of improvements to revetments, retention basins, regulating reservoirs and diversion channels. Project currently underway in the low-lying eastern areas include storm water detention facilities, inner river development projects, super levee development projects, and earthquake reinforcement projects. Some of these projects include construction of tide embankments, water gates and seismic reinforcements to preventing damage from storm surges and earthquakes. In addition, the TMG is also involved in erosion and sediment control projects, landslide control projects, and landslide prevention projects. Rivers are valuable open spaces that can improve the quality of life of residents in densely populated urban areas. Numerous projects have been conducted to create aesthetically pleasing riverside environments with revetments that facilitate the access of users to water. The TMG is now promoting integrated flood control measures that balance the basic policy requirements for flood control systems in the Tokyo metropolitan area with the needs of the public.

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