A Study on River Space Restoration and Improvement of Water Quality in Nihonbashi River

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ABSTRACT: Nihonbashi River takes more time to discharge water pollution because it runs low-lying areas and is easy to affect tidal flow from downstream. After rainfall, the water environment of the river has become worse. Even though the river is located in the important metropolitan area in Tokyo, it dose not have any connection with people's lives. We took Nihonbashi River as an example to consider methods for river restoration of improving water quality and river environment in densely inhabited urban areas. Especially, the major issue of river restoration is how smoothly and quickly discharges water pollution which flows into with river flow. The conclusion of this project is the effectiveness of improvement of water environment to construct of rock gates in Nihonbashi River and Kanda River to control inflows from upstream and tidal flows from downstream.

1 INTRODUCTION

In the past, the Nihonbashi River was running through the central area of Edo culture, and represented the history and the lively culture of Edo. However today, it is a drainage river with many combined sewers in the densely inhabited urban area surrounded by numerous buildings. Moreover, the Nihonbashi River runs low-lying areas, thus has physical features such as slow flow speed, sensitivity to tidal flows, detention of polluted water. For these reasons, particularly after rainfalls, its water environment remains considerably poor. This has made the river loose in touch with civil society regardless of its being located in the important part of the urban area.

Against such background, this study, by analyzing the case of the Nihonbashi River as an example, aims to consider methods for restoring urban rivers that are located in densely habited urban areas through water quality improvement and river space restoration.

Particularly, it is a major issue regarding river space restoration how to smoothly and quickly discharge polluted water that flowed into the river due to flooding. In this study, a hypothesis that the water quality of the Nihonbashi River can be improved through accurately controlling both the flow from upstream and the backwater from downstream due to tidal flow, by establishing lock gates on the Nihonbashi River and the Kanda River.

2 CURRENT STATE AND ISSUES OF THE KANDA RIVER AND THE NIHONBASHI RIVER

The Kanda River flows down through cities such as Shinjyuku City, Toshima City, Chiyoda City, Chuo City in Tokyo, while the Nihonbashi River is its tributary on the right side. These two rivers, as well as discharge from the Sotobori that flows into the Kanda River during flood, constitute a river network (Fig.1)

In the following, the overview and current state of water quality of these rivers as well as their historical background in terms of river space will be introduced.

2.1 Over View of the Kanda River

The Kanda River, whose total length is about 25.5km, takes its water from the spring water in Inogashira Park in Musashino City, Tokyo. Its basin includes cities such as Musashino, Suginami, Nakano, Shinjuku, Toshima, Bunkyo, Chiyoda and Chuo. In this study, the target section of the Kanda River is: the section from the Takadabashi Bridge that is contiguous to low-lying downstream area to the branching point from the Nihonbashi River at the downstream Suido Bridge and the point where it flows into the Sumida River near the Ryogoku Bridge.

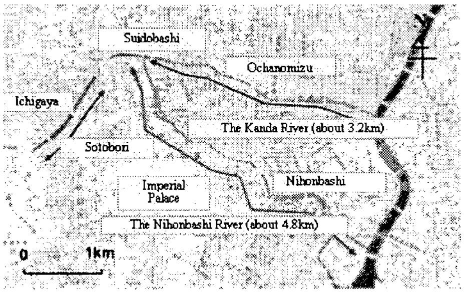


Fig.1. Location of the Nihonbashi River

2.2 Over View of the Nihonbashi River

The Nihonbashi River, whose total length is about 4.8km, diverges from the Kanda River at the Koishikawa Bridge at the upstream of the Suido Bridge, and runs through the central areas of Tokyo such as Iidabashi, Otemachi and Nihonbashi into the Sumida River near the Eitai Bridge. Its basin includes Chiyoda City and Chuo City.

2.3 Over View of the Sotobori

The Sotobori is the site of the outer moat of Edo Castle, which today remains along JR Sobu Line from Akasaka-mitsuke to Iidabashi, and its water runs through Yotsuya and Ichigaya surrounding the Imperial Palace to flow into the Kanda River through a channel near Iidabashi Station.

In the Sotobori, algae bloom that accompanies eutrophication can bee seen due to the stagnation of the spring water flows and small amount of rain water. Moreover, during flood, such polluted water is discharged into the Kanda River near Iidabashi, which results in the algae's floating in the Kanda River.

2.4 Current state of the water quality

The water quality of the Nihonbashi River is dependent on those of the Kanda River and the Sotobori, as well as the wastewater which is discharged into the Nihonbashi River through combined sewer system.

2.4.1 Water Quality of the Kanda River

In the upper course of the Kanda River, as the discharge from Water Reclamation Center in Ochiai and Nakano flows into, its water volume is affluent. The water quality meets the type C of environmental quality standards (BOD: 5mg/l), however, there is occurrence of scum and malodor, which is possibly due to the inflow of wastewater from the Sotobori. Particularly, the scum frequently occurs near Iidabashi. Moreover, during rainfall, untreated concentrated wastewater flows into the river through combined sewer system, and tide level change causes backflow phenomenon in the Sumida River, to which the water from the Kanda River is discharged. This makes the recovery of water quality to take several days after the rainfall. At the branching point from the Nihonbashi River, part of such polluted water flows into the Nihonbashi River.

The current state of water quality of the Kanda River can be summarized as follows:

- The Its BOD meets the chemically defined environmental quality standard (Fig.2)
- The inflow of turbid water, in relation to the tide level of its discharge destination, makes the recovery of water quality take long time and its condition remain poor.
- As it is connected to the Sotobori through channels, water-bloom occurred in the Sotobori flows into the Kanda River, which also affects on the water of the Nihonbashi River
- Same as the case of the Nihonbashi River, its water retention in the downstream estuary is worsening its water quality.

2.4.2 Water Quality of the Nihonbashi River

The water quality of the Nihonbashi River also meets the type C of environmental quality standards (BOD: 5mg/l) as shown in the Fig.2, however, its nitrogen level and phosphorus level are high, which creates an environment where phytoplankton and algae can easily grow.

In the Sotobori, its water hardly circulate, which causes the explosive increase and growth of phytoplankton, which flows into the Kanda River and the Nihonbashi River as water-bloom. Moreover, its flow speed is slow due to the low river gradient, which makes it difficult to flow out the polluted water that has flowed into the river. Also during rainfall, untreated wastewater together with the rain water flows into the river through the combined sewer system. The current state of the water quality of the Nihonbashi River can be summarized as follows:

- It's BOD meet the environmental quality standard, however, it provides an environment for phytoplankton to grow easily, which together with the inflow of water-bloom and scum, worsen the image of the water quality of the Nihonbashi River.
- The source of the pollution is the inflow of polluted water from the upper Kanda River, The Sotobori and the combined sewer system during rainfall.
- Due to its low river gradient, its flow speed is slow, which causes the water retention at its downstream estuary and worsen the water quality.

2.4.3 Water Quality of the Sotobori

The Sotobori takes its water from the small amount of spring water flows and the input of rain water, hence its water does not circulate and causing detention. For this reason, water-bloom grows explosively and malodor occurs in the Sotobori during summer. The inflow of polluted water from the Sotobori to the Kanda River and the Nihonbashi River is part of the water quality problems such as water bloom.

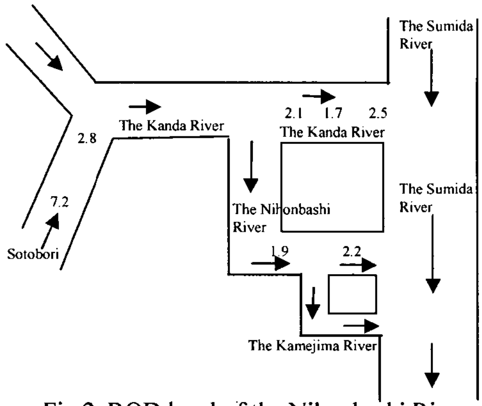


Fig.2. BOD level of the Nihonbashi River

3 HISTORY AND CURRENT STATE OF THE NIHONBASHI RIVER'S RIVER SPACE

3.1 History and current state of the Nihonbashi River's River Space

Fig.3 shows the river banks of Tokyo in the Meiji Period. Then, the prime mean of physical distribution was river boat, and the rivers were the prime route for physical distribution. Therefore, there were numbers of river banks on riverside. From the existence of the numerous river banks, it can be assumed that the riverside space, where various goods are exchanged, was a lively living space for the people of that time. This also suggests that people were familiar with riverside space in Tokyo even in the past.

Picture.1 is the aerial photograph that shows the state of the Nihonbashi River in 1947. As it was taken before the construction of the Metropolitan Expressway, the Nihonbashi River was not yet covered with elevated bridges, and it can be seen that the river was visible also in front of Tokyo station. This picture reveals that there were many moats and rivers in the area where currently known as Chiyoda City and Chuo City in 1947, and they were neither covered with elevated bridges nor reclaimed at this point.

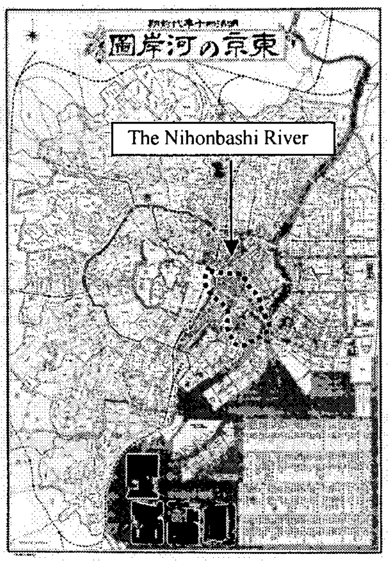
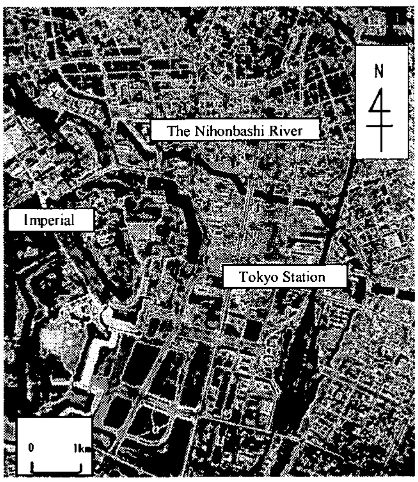
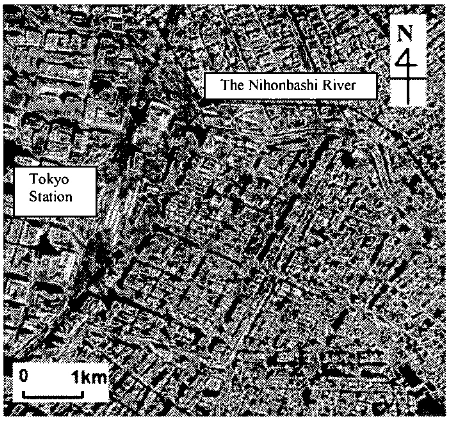


Fig.3. River Bank in Tokyo in the MEIJI Period



Picture.1. Aerial Photograph of Tokyo Station Area (1947)



Picture.2. Aerial Photograph of Tokyo Station Area (1986)

Picture.2 is the aerial photograph that shows the state of the Nihonbashi River in 1986. By this point, the construction of the Metropolitan Expressway had been already completed, hence the river is invisible in this photograph taken from above. The photograph also reveals that the area around the Nihonbashi River was closely packed with buildings. Thus, the Nihonbashi River has lost its riverside space.

The history of the Nihonbashi River and its river space can be summarized as follows:

- In the Meiji Period, river boat was the prime mean of physical distribution, and there were numbers of river banks by the Nihonbashi River.
- As part of the social infrastructure improvement towards the 1964 Tokyo Olympics, the Nihonbashi River was covered with the Metropolitan Expressway.
- Since then, rapid improvement of social infrastructure continued, in which the Nihonbashi River lost is river side space.

3.2 Current State of River Space

Fig.4 is the map based on field observation which shows the current state of riverside space of the Nihonbashi River.

- In some sections of the river, desirable pedestrian spaces are established such as the case of Iidabashi Eye Garden Air in the upper reach (Picture.3).
- However, overall, pedestrian space on the riverside is very limited (about 70%).
- Many riverside spaces are occupied with buildings and car parks, which hampers people's access to the river (Picture.4).
- Except emergency jetties, facility and space which lead to the waterfront are not developed.

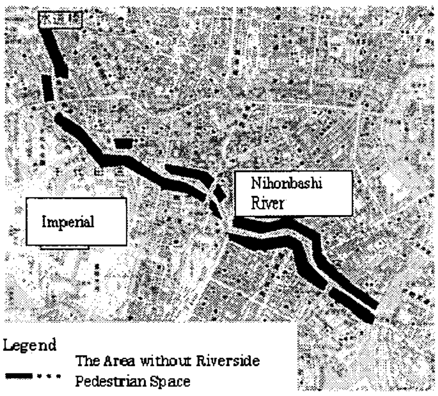
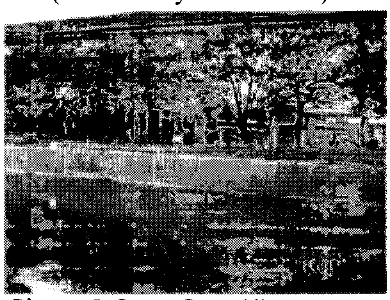


Fig.4. Current State of the River Space along the Nihonbashi River

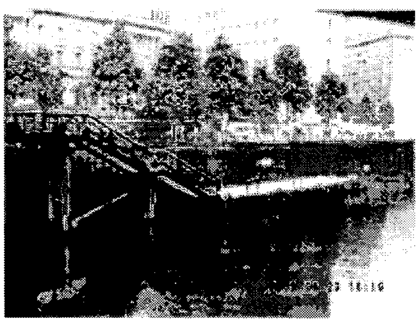
In addition, these emergency jetties are normally locked and not open for the public (Picture.6)

Picture.3. Space State (1) (Iidabashi Eye Garden Air)

Picture.4. Space State (2) (A Building at Watershed and Elevated Bridge of the Metropolitan Expressway)



Picture.5. Space State (4) (Concrete Bank Protection)



Picture.6. Space State (4) (Emergency Jetty)

3.3 Problems of the Nihonbashi River

The major problems of the Nihonbashi River areas "water pollution" and "lack of pedestrian space and recreation space on the riverside".

The main problem structure of the water pollution is that the water stagnates and gets polluted in the Sotobori, where water does not circulate, and the polluted water flows into the Kanda River and the Nihonbashi River.

Another cause of the water pollution is the untreated wastewater from combined sewer system that flows into the river during rainfall. In addition, being a tidal river, backflow from its downstream, the Sumida River, occurs during an incoming tide of Tokyo Bay. Also, because of its slow flow speed due to low river gradient, once its water becomes polluted, it stays in the river and the recovery of water quality takes long time.

As the Nihonbashi River is located in the metropolitan area in Tokyo, its river space is occupied with buildings and car parks, which makes it difficult to establish continuous pedestrian space on the riverside and the people's access to the waterfront.

The above problems of the Nihonbashi River can be summarized as follows:

<Water Quality>

- The inflow of the water from the upper Kanda River and the Sotobori as well as the wastewater from the combined sewer system during rainfall
- Water stagnation at the downstream estuary

<Riverside Space>

- Limited pedestrian space on the riverside
- Limited riverside space that provide access to the waterfront due to its being surrounded by numerous buildings

4 The River Walk for the Utilization of River Space

4.1 Current State of River Space of Nihonbashi River

The elevation of the levee at the downstream end of the Nihonbashi River is set as AP5.1m of the tidal wave's design sea level, and its crown elevation is set as AP5.5m which includes the additional 0.4m as allowance height. If tidal wave can be controlled, the crown elevation will be determined according to overflow elevation. That is, by subtracting the tidal wave elevation, it may become possible to make the current crown elevation 2.9m lower at maximum (Table1). This will probably allow an urban development in harmony with the waterfront. However in this case, installation of drainage pumps in case of the flooding at high tide.

Table1. Levee Elevation of the Nihonbashi River and Design Water Level

1) Crown Elevation of the Nihonbashi River's Levee Revetment	Ap 5.5m
2) Estimated high-water level	Ap 5.1m
3) Tidal wave elevation	2.9m
4) Tidal wave elevation subtracted [1)-3)]	Ap 2.6m
5) Current riverbed elevation (Average)	Ap-2.5 ~ -2.0
6) Surrounding ground elevation (Average)	Ap 4.0 ~ 5.0
7) Tidal level variation at Tokyo Bay (Reiganjima 2004-2006)	Ap-0.33 ~ 2.67
8) Average tidal level at Tokyo Bay (Reiganjima 2004-2006)	Ap 1.15 ~ 1.23

4.2 Suggestions on River Space Based on the Current Local Terrain

The width of the Nihonbashi River is 30m in the upstream, while 60m in the downstream. As for the current river channel section, its riverbed elevation is from Ap-2.5 to Ap-2.0m, while its land elevation is from Ap+4.0 to Ap+5.0m. This creates a valuable urban area with the width of 30-60m, height of 6.5-7.0m and the total length of 4.8km.

In Tokyo, the average number of days with rainfall is about 80, hence during the rest of the year (285 days), a space with the average water level of Ap+1.2m, the maximum water level of Ap+2.67m and the minimum water level of Ap-0.33m is available. Particularly, based on the water level after subtracting the tidal wave elevation (Ap+2.6m) (Table-1, 4)) and the maximum water level in Reiganjima during the past 3 years (Ap+2.67m), the development of a riverside pedestrian space (River Walk) at the level of between Ap+2.5 and Ap+3.0m can be considered. Such pedestrian space will not be flooded on the days without rainfall (285 days/year), thus would allow securing of a valuable pedestrian space in the urban areas. In addition, if the constant water level on the side of the Nihonbashi River Walk can be maintained by establishing a lock gate at the confluence with the Sumida River, it would not only establish a pedestrian space but also a recreational space on the riverside, which would contribute to the urban development in harmony with the waterfront. Also, when the Sumida River's water level is low such as after flood, a high-speed flow from the Nihonbashi River to the Sumida River can be artificially created by the opening operation of the lock gate, which would promptly discharge the polluted water from the Nihonbashi River. As previously shown in the Fig.4 in (2) of Section 3, the Nihonbashi River runs through the central area of Tokyo, hence most of its riverside spaces are occupied with buildings or used as car parks, and riverside pedestrian space is very limited.

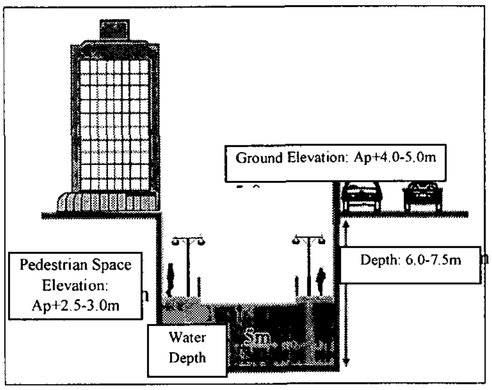


Fig.5. Image of the River Walk along the Nihonbashi River

4.3 Structures for Water Level Control

In addition to the River Walk that is free from flooding for 285 days per year, by establishing lock gates at the confluence of the Kanda River and the Sumida River as well as at the confluence of the Nihonbashi River and the Sumida River and conducting their operations, the Nihonbashi River's water level can be kept constant when the Sumida River's water level is low and the polluted water can be discharged through lock gate operation after flooding.

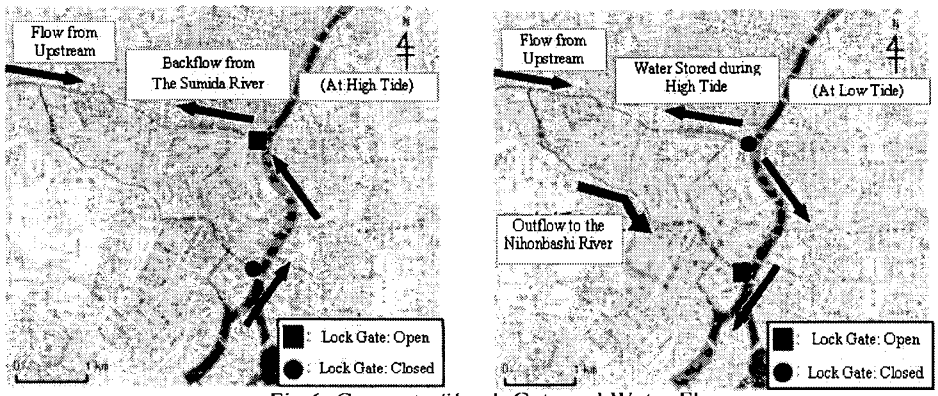


Fig.6. Concept of Lock Gate and Water Flow

4.3.1 Water Retention at High Tide

By opening the lock gate at the downstream end of the Kanda River while closing the lock gate at the downstream end of the Nihonbashi River, the backwater from the Sumida River flows into the Kanda River and the Nihonbashi River, thus water retention near the high tide level becomes possible.

4.3.2 Discharge at Low Tide

By keeping the lock gate at the downstream end of the Kanda River closed while opening the lock gate at the downstream end of the Nihonbashi River, the water will be discharged at the altitude difference of 2-3m from the water level of high tide (from Ap+2.0m to 2.67m) towards the Sumida River's water level (from Ap-0.33m to 0.0m), which will be applicable to the pollution discharge etc.

4.3.3 Water Level Control for the River Walk

As for how to keep the Nihonbashi River's water level constant, it can be achieved through reserving backwater from the Sumida River by establishing lock gates at the watershed of the Kanda River and the Nihonbashi River as well as at the both sides of the downstream end of the Nihonbashi River. Also, when small-medium scaled floods occur, desirable water quality of the River Walk can be secured by preventing the inflow of pollution from the Kanda River through keeping the lock gate at the watershed closed. After floods, polluted water directly discharged from the combined trunk sewer can be released from the operation described in 2).

5 WATER QUALITY IMPROVEMENT THROUGH THE OPERATION OF LOCK GATE

5.1 Hydraulic Characteristics of Lock Gate Operation

The hydraulic behaviors in the Nihonbashi River and the Kanda River were analyzed with MIKE11, covering the period from 4th to 11th of September, for which the data on gauged rainfall, water level etc. were provided by the Tokyo Metropolitan Government.

The flood on the 4th of September, 2005 occurred due to a heavy rainfall mainly in the downstream area of the Kanda River System, and 96mm of moderate total rainfall was recorded at the Chuo Gauging Station (in Otemachi).

The runoff volume from the Kanda River and its basins was calculated based on the Time-Area method, and the water level of the Sumida River was taken from the record of the Reiganjima Gauging Station near the confluence of the Kanda River and the Nihonbashi River. Thus, hydraulic characteristics such as regurgitant flow and water level change were analyzed in unsteady flow calculation. In this analysis, it was assumed that lock gates will be established at the downstream ends of the Kanda River and the Nihonbashi River, and the operations according to the water level of the Sumida River will be conducted such as the detention operation that only allows backflow when the water level is high, followed by the discharge operation when the water level lowers. From this analysis on hydraulic characteristics, the following findings were obtained:

5.1.1 Difference of the water level change between Sumida River and Nihonbashi River

While the water level change of the Sumida River was 2.0m, the water level change at the watershed of the Nihonbashi River was only 0.5m.

This indicates that although the water level change at the estuary of the Nihonbashi River was 2.0m, due to the fact that the watershed is 4.8km away from the estuary and the maximum slope of water surface is only 1/9,600, enough amount of backwater could not be gained.

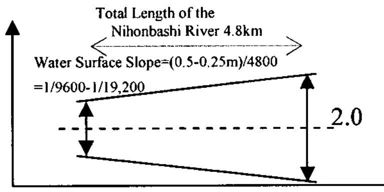


Fig.7. Concept of Hydraulic Characteristics

5.1.2 Backflow Detention by Lock Gate Operation and Effect of Water Level Lowering

For backwater detention, lock gate operation according to the water level of the Sumida River is indispensable. That is, backflow needs to be allowed when the water level is high, while discharge needs to be halted by closing operation when the water level is low. By repeating such operations, it becomes possible to keep the water level of the Nihonbashi River at high tide level.

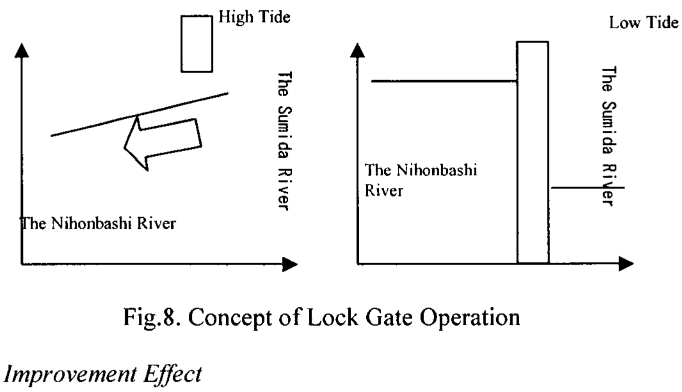


Fig.8. Concept of Lock Gate Operation

5.1.3 Water Quality Improvement Effect

As the hydraulic characteristics indicate, the hydraulic behaviors at the river estuary have an effect of accumulating pollution in the river channel. Therefore, once polluted water flows into the river channel by flooding, it will stay there for long term. In the case of the flood on 4th September, 2005, which only lasted for 3 days, it takes 7 days for the intake of polluted water to be released according to a simulation.

As an early solution for this problem, while the water including pollution is accumulated (Fig.8, Right), the gate can be opened to release the polluted water when the water level of the Sumida River (discharge destination) is at low and its water-level difference from the Nihonbashi River becomes largest.

However, installing a lock gate only at the estuary will delay the release of the pollution. The case of the September 4 flood also indicates that it takes 4 days for the discharge without lock gate, however 4 days and 14 hours is required if the lock gate operation is conducted.

In order to avoid this phenomenon, there is a method of controlling the inflow of pollution from the upstream (the Kanda River), that is to conduct lock gate operation at the watershed for avoiding the inflow of flood water.

Keeping the lock gate on the upstream side at over Ap+2.5m will enable avoiding the flood water inflow from the Kanda River, which will limit the discharge volume to that of the Nihonbashi River basin from its upstream to the watershed. As assumed by the scale of basin area, this will reduce the target pollution amount to less than one-fifth, and enable rapid discharge.

As the result of a simulation on the rainfall from year 2004-2005, it was found that among all the rainfall events of over 80 times per year, the rainfall events that exceeds Ap+2.5m at the watershed of the Nihonbashi River occurs when the total rainfall measured at the Chuo Gauging Station exceeds about 30mm (15 times, about 20%).

Therefore, its occurrence is about for 20 days out of 365 day, hence the number of overflow days will be less than 10% of the whole year. Also, as for the changes in BOD level during the 8 days from 4th to 11th September, assuming the conduction of the operation for avoiding the overflow from the Kanda River, the average change was from 6.2ppm to 4.4ppm, while the maximum change was from 36.4ppm to 24.6ppm, that is 30% reduction in average and 33% reduction at maximum.

Thus, despite the complexity of lock gate operation, it was found that the establishment of a lock gate at the watershed will be highly effective in water quality improvement of the Nihonbashi River.

6 SUMMARY

6.1 Conclusion

In this study, the current state of the Nihonbashi River was analyzed, through which its problems regarding water quality and river space was revealed, and lastly solutions for these problems were examined.

As for the solution regarding water quality, by establishing lock gates at the both ends of the Nihonbashi River and preventing the inflow of flood water when the total rainfall is below 30mm, water quality can be improved for about 90% of the whole year.

In terms of the spatial solution, the possibility of developing a riverside pedestrian space by maintaining the constant water level was demonstrated. The lock gate operation to direct water utilizing the water level of the Sumida River aimed at water quality improvement can also be effective as the operation for keeping the constant water level, which enhances the potential for the establishment of a river walk that is close to the waterfront, which thus enables the urban development in harmony with waterfront.

To allow people to use river space as an urban space, it is essential to secure desirable water quality and recreational space near the waterfront. In this study, it was proved that the establishment of lock gates in the Nihonbashi River and the Kanda River, more concretely the operation of these gates for water diluting and purification as well as water level control, will be effective as a solution for the problems of the Nihonbashi River regarding water quality and river space. As in this study, by linking the diluting and purification of water quality with the development of river walk, a prospect for the Nihonbashi River restoration will rise. It should be also noted that discussions on the removal of express highway that has no specific time frame for implementation is not a sufficient enough, hence other approaches such as those suggested in this study should be considered first/simultaneously.

6.2 Future Prospect

In this analysis, the establishment of lock gates at the point where Lower Nihonbashi River and the Sumida River meets the Sumida River as well as the branching point of the Upper Nihonbashi River and the Kanda River was simulated. In future studies, it will be necessary to figure out a steady operation method by modeling the details of combined rainwater drainage in the basin as well as by the examination of specific pollution behaviors with the model including the inflow process of the pollution load during limited rainfall.

7 REFERENCES

1) Chiyoda City: "City Planning Master Plan for Chiyoda City", pp.28-31, 1998.03

2) Ministry of Land, Infrastructure and Transportation ,"General Technology Development Project, Report on the Development of Land Infrastructure Technologies in Accord with Nature", pp.540-589, 2005.10

3) Technology Research Center for River Front Development: "Japan's Water Villages and Aquapolises – Emotional and Recreational Space to Engage with Water", pp.100-111, 2006.03

4) Yoshikawa Katsuhide, "River Basin Environmentlogy – River Engineering for the 21st Century", GIHODO SHUPPAN Co., Ltd., pp.198-226, 2005.03

5) Yutaka Takahashi, "River Engineering", University of Tokyo Press, pp.36-76, 2002.03

6) Bureau of Construction, Tokyo Metropolitan Government, "The Current State and Future Issues of the Kanda River", <http://www.kensetsu.metro.tokyo.jp/kandagawa_saisei/index.htm>