8 - 1 Feasibility Study on the Real-time Control System of the Pumps for the Reduction of Combined Sewer Overflows

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Abstract

The sewerage system for Metropolitan Tokyo has reached 100% target fulfilment for the Tokyo Wards over the long period of more than a century. Because of the hastiness with which the wastewater collecting system and the flood prevention measures for the low-land areas have been developed simultaneously, approximately 80% of the present facilities are of the combined sewer type collecting both wastewater and stormwater in a same sewer pipe.

The problem with the combined sewer system is that water pollution occurs in the receiving water bodies into which wastewater is discharged as a result of the combined sewer overflow (CSO) in wet weather conditions. A few years ago, a white coloured solid mass (consisting of oil and fat that adhere to the inner walls of sewers and are discharged with the CSO solidifying in the shape of balls) was spotted in a place on the manmade shore of the Bay of Tokyo, a discovery that aroused great concern among the public. In response to this event, the Study Committee for Combined Sewer System Improvement was appointed to look into the problem. As a result, policy proposals for action on national level were formulated.

With regard to flood problems, there has also been an increase in the volume of stormwater runoff as a result of the rapid pace of urbanization in recent years, and sudden intensive outbursts of torrential rain brought about by the heat island phenomena are occurring more frequently. These problems have created a need for countermeasures at a higher level.

While it is necessary to expand the infrastructure hardware in terms of a reinforcement of the facilities and a shift to the separate sewer system in order to address these issues, the problem is that it would take a long time and a major investment commitment to complete the work. Tokyo Metropolitan Government (TMG) has therefore decided to make the maximum possible use of the existing facilities while ensuring safety against inundation and to promote measures also from a software approach by introducing a system capable of minimizing combined sewer overflow, the real-time control (RTC) system.

A pilot RTC system was introduced in August 2001 for the Shinozaki Pumping Station’s catchment area, which covers a stormwater runoff area of approximately 2,100 hectares. Bypass pipes interconnect the two trunk sewers, that is, the Shinozaki district and Shibamata district trunk sewers, and stormwater is drained off by the three Pumping Stations connected to the Shinozaki trunk sewer while the remainder is
removed at the Shinozaki Pumping Station at the downstream end. The RTC system monitors the precipitation volume in the catchment area and the water level of flow in the pipe. On the basis of these data, the gates and drainage pumps are operated while making optimum use of the water storage capacity of the pipes to achieve the effective removal of contamination in stormwater. In the development of this system, extensive use was made of state-of-the-art technology, including the use of water level gauges by optic fibre technology suited for measuring the water level inside pipes and the combination with a rainfall data system by radar rain gauges.

Simulations were carried out on the basis of past rainfall data. From the results, it was found that with the use of the RTC it is possible to reduce CSO by roughly 50% for small rainfalls with a total precipitation level of 20mm or less by storing stormwater in the pipe routes at the beginning of the rain. It has also been shown that CSO can be reduced by about 80% through the use of rainfall forecasting.

This article presents the methodology used for the implementation of a fact-finding study of the rain volumes in catchment area and water levels in the sewer and gives an overview of the results. It also includes a description of the RTC system structure, the method of developing and calibrating hydraulic models, the development of the operational support and operating roles and the effect achieved in terms of reducing CSO.

Keywords: Combined Sewer Overflow, Modelling, Real-time Control

1. Introduction

The sewerage system in Tokyo has a long history, going back over more than a century since the construction of the Kanda district sewer that heralded Japanese modernised sewerage system. The development of the sewerage system eventually reached a 100% level of target fulfilment for the Tokyo wards area in 1995. Scales of sewerage system are total length of sewers by 15,000km, numbers of pumping stations by 78 and numbers of wastewater treatment plants by 14. Some of the wards have large lowland areas posing a high risk of flooding, and in the development of this vast sewer system great emphasis was laid on flood protection measures in concern with wastewater disposal. In view of this, the combined sewer system, which collects both wastewater and stormwater, was adopted. As a result, virtually the entire sewer system now consists of combined sewers, while the separate sewer system, which is reputedly superior to the combined sewer in terms of pollution prevention, accounts for only 18%.

In combined sewers, during rainstorms, there is no alternative but to let the amount wastewater that can no longer be treated overflow with the stormwater as combined sewer over flow (CSO). From this fact, the combined sewer carries a risk of causing water pollution in receiving water bodies. This CSO problem has recently aroused much attention in view of the advanced development of the sewerage
infrastructure and the dramatic improvement in the aquatic environment, with the public showing an increasing interest in the waterfront. In recent years, the environmental standards for rivers have been tightened further and new efforts to improve the water quality of the Bay of Tokyo have been initiated. Amidst these efforts it is necessary to take measures towards improving the environment.

In this context, efforts have been made to raise the efficiency of sewage containment removal and to create storage reservoir and pipe capacity as a means of improving combined sewer operation, it will still take considerable time and costs to complete these projects amidst the strained financial situation in Japan facing at present. Under these conditions, the news press reported in October 2000 that lumps of a foul-smelling white solid mass had floated onto the beaches of the Odaiba Coastal Park overlooking the Bay of Tokyo. The formation of this contaminant mass (oil ball contamination) is caused by oils and fats that adhere to the internal wall of sewer pipe and are washed away down the sewer with the stormwater overflow. This discovery was a serious shock to all of us who are working in the field.

In response to this incident, the government recognized the need not only for the conventional measures to prevent flooding but also for improving the combined sewer system itself, and took action by appointing the Study Committee for Combined Sewer System Improvement to promote measures on a nationwide scale. The Committee summed up its policy findings in a report made public in February 2002.

After the incident, Tokyo Metropolitan Government (TMG) immediately examined the possible countermeasures and drew up its “Quick Plan for Combined Sewer System Improvement” as an emergency measure in March 2001. One of the measures embraced in this Plan is to introduce a Real Time Control (RTC) system to help improve the combined sewer system by making more effective use of the existing facilities for stormwater storage while maintaining the safety standards for inundation.

Apart from the fact that priority had always been given to the development of the sewer network, another reason why the RTC system had not been introduced in Japan before is due to fears that the use of the sewer pipes as stormwater storage reservoirs might lead to a delay in the actuation timing to start the stormwater pumps and thus cause flooding accidents, seeing that the changes in the water level inside the pipes occur very abruptly and that it takes little time for the stormwater to reach the Pumping Station. At present, however, considerable progress has been made in the development of the sewer infrastructure in upgrading the control technology. Optic fibre water level gauges are used for measuring the water level inside the pipes, which can be installed in almost any position because there is no regulation for installation due to not being required a power supply. With the use of optical fibre communications networks it is also possible to transmit the measurement data over long distances. The precipitation measuring techniques using radar rain gauges have also achieved significant advances, leading to improved rainfall forecasting accuracy. As a result of these technical engineering advances, conditions have been met to
permit the effective use of RTC system for operating gates and pumps in sewer networks.

The Shinozaki Pumping Station’s catchment area that is targeted for the introduction of RTC system has a simple sewer network system. Since it has a relatively long and large trunk sewer it is capable of being used as a storage pipe. The use of the RTC system is designed to reduce the frequency of drainage of stormwater pumps and thereby it can decrease CSO events.

2. Combined Sewer System Improvement

The above oil ball incident prompted the government to appoint the Study Committee for Combined Sewer System Improvement (CSSI). The Committee consists of experts from the relevant technical-academic spheres, the relevant ministerial agencies, and the regional and local governments. It promotes measures for CSSI on a nation-wide scale and summed up proposals of measures for CSSI in a report made public in February of 2002.

Given as targets to be accomplished on a rough time scale of ten years are the objectives of reducing the pollutants load, ensuring safety in terms of public hygiene, sanitation and preventing the overflow of impurities such as oil-ball contamination. To achieve these goals, the Committee has specified its targets from three viewpoints through the implementation of preliminary monitoring of the combined sewer system, the establishment of CSSI plans for all cities using this type of sewer and intends to promote these improvement programs on the basis of a fixed schedule. A post-project monitoring study is also due to be carried out in order to verify the effectiveness of the proposed measures and its findings are to serve as feed-back data for further improvement programs. In terms of reducing the contamination load, the plan targets to reduce the effluent BOD contaminant load to a level below that of the separate sewer systems. To ensure greater safety from the viewpoint of sanitation and public hygiene, the objective targets to halve the frequency of overflow at stormwater outlets and at all stormwater pump installations. In order to reduce the overflow of impurities, appropriate measures are provided to prevent their overflow at stormwater outlets and at all stormwater pump installations.

As a result of these efforts it should be possible to reduce the annual BOD contaminant load that is discharged from the combined sewer systems in rainy conditions from the present level of approximately 70,000 tons to about 19,000 tons within ten years. It should also be possible to halve the frequency of untreated sewage overflows and to prevent the discharge of impurities. The result should be a significant improvement in the water environment of the water system that receives the sewage overflow.

One of the main concerns for the development of the facilities for improving the combined sewer system when urban development takes place on an area-wide basis is that efforts must be made to separate the flows of the combined sewer areas, and that
some fundamental measures, including the storage of stormwater and full permeation of stormwater have to be taken simultaneously.

The most important areas of development for the technologies needed to improve the combined sewer facilities are such technical developments as will be necessary for the effective improvement of the combined sewer system, including the effective detoxification of wastewater at the water clarification systems, the development of highly efficient and effective treatment technology for water clarification, and the establishment of RTC technology for the facilities coupled with effluent volume prediction. These technologies have to be developed in order to pave the way for effective improvements in combined sewer systems.

TMG has been committed to its own project for combined sewer system improvement. These improvements of the combined sewer system are designed to create a comfortable waterfront environment and to reduce the contamination load to 23 wards area of Tokyo.

Figure 1 - Tokyo map showing the study area
the same level as that achieved with the separate sewer system. Until the present, a variety of projects have already been carried out for the treatment system. These works include a stormwater reservoir in wastewater treatment plants capable of storing an amount of stormwater equal to double the dry weather flow in one hour and a wet weather reservoir (pipe) at pumping stations capable of storing a stormwater volume more than three times the dry weather wastewater flow, that is, an amount of 8mm rainfall depth in catchment area. The completion of these initial-stormwater reservoirs will require considerable time and vast investment amounts.

As an emergency measure, the “Quick Plan for Improving the Combined Sewer System” has therefore been established and RTC system has been phased in gradually to improve the combined sewer system. One of the menus for its promotion is the integration of control data in real-time, including rainfall volume, water level in the sewer pipes, and pumps operational information, while making effective use of the existing large sewers, with the safety against inundation maintained as it is.

3. Introduction of the RTC System

3.1 Catchment Areas Scheduled for System Introduction

As can be seen in Figure 1 and Figure 2, the catchment area in which the RTC system is to be introduced is the catchment area serviced by the Shinozaki Pumping Station. This catchment area is located in the southeastern part of Tokyo and has large-scale combined sewer facilities with two trunk sewers, the Shinozaki and the Shibamata sewers. The diameter of the end sewer is 7m and the stormwater drainage surface approximately 2100 hectares. In this large catchment area there are a total of four pumping stations in the catchment area with a designed drainage capacity of 128m³/s. The two trunk sewers are interconnected by three bypass pipes. The Shinozaki trunk sewer has four pumping stations. Three stormwater pumping stations on the upstream end discharge the stormwater into the river, and the Shinozaki pumping station on the downstream sends wastewater to Kasai treatment plant and drains stormwater into the river. The confluence of the three upstream pumping stations and Shinozaki trunk sewer takes the form of an overflow weir and a manhole with an orifice (separator manhole). When the stormwater exceeds an amount of three times that of the maximum hourly wastewater flow, the water flows from the separator manhole to the pumping station and is then discharged into the river without being treated. The remainder is sent to the treatment plant through the trunk sewer via the Shinozaki pumping station located farthest downstream. Table 1 gives the data for the Shinozaki pumping station catchment area. At present, the three upstream pumping stations are operated under remote control from the Shinozaki pumping station, and it is possible to operate them in concern with the Shinozaki pumping station during wet weather.
Since a considerable part of the metropolitan infrastructure is concentrated in this catchment area and because of the high density of housing and the high proportion of asphalt paving in the area, this location has stormwater runoff rate of around 0.7. As a result, the stormwater flows into the pipe in a sudden burst in large volumes during rainstorms. (Thus, for example, on August 25 - 26, 1997, the rainstorm falling in 10 minutes amounted to 24mm, and to 48mm in 20 minutes.) Observation has shown that it takes only a short time of 10 - 30 minutes from the outbreak of rain to water runoff. In order to achieve the high reliability needed for operation, it is essential to operate the pump in accordance with the sudden rise in water level. To achieve this, the standby pumps have been installed at the Shinozaki pumping station. Standby pumps are capable of operating in air and can be started before the stormwater arrives. This

Figure 2 - Shinozaki pumping station Catchment Area
makes it possible to quickly respond to the conditions.

### Table 1 - Data for the Shinozaki Pumping Station

<table>
<thead>
<tr>
<th>Item</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Shinozaki Trunk Sewer</td>
<td>Approx. 12km</td>
</tr>
<tr>
<td>Maximum diameter</td>
<td>7m</td>
</tr>
<tr>
<td>Design area</td>
<td></td>
</tr>
<tr>
<td>Wastewater</td>
<td>2,097ha</td>
</tr>
<tr>
<td>Stormwater</td>
<td>2,108ha</td>
</tr>
<tr>
<td>Design drainage flow rate</td>
<td></td>
</tr>
<tr>
<td>Shinozaki Pumping Station</td>
<td>88.119m³/s</td>
</tr>
<tr>
<td>Nijuku Pumping Station</td>
<td>13.000m³/s</td>
</tr>
<tr>
<td>Hosoda Pumping Station</td>
<td>14.000m³/s</td>
</tr>
<tr>
<td>Koiwa Pumping Station</td>
<td>13.000m³/s</td>
</tr>
</tbody>
</table>

3.2 System Function

Figure 3 shows a conceptual view of RTC system. Based on such data as the rain volume, the water level in the pipes, and the operating status of the pumps, the pumps and movable gates are prepared, operated and controlled in an effective manner to provide a measure against CSO by using the discharge and storage capacity of the stormwater discharge facilities during conditions of small rainfall amounts.

![Figure 3 - Conceptual View of the RTC System](image)

The RTC system performs predictions of the rainfall, inflow volumes and of the water level in the sewer pipes by using the data from the ground rain gauges at the
individual pumping stations and from the optic fibre water level gauges installed in 11 locations in sewer networks. To predict the runoff volume of the catchment area with a few or ten minutes after the outbreak of rain, it is essential to predict both the rainfall and the runoff volumes. Especially for operating the drainage system in real-time, the area distribution of the rainfall volume is an important boundary condition. The accuracy of these predictions are closely related to the prediction accuracy for the water level and flow rate. This system therefore predicts variations of rain volume over the area of the catchment area in the course of time. By forecasting runoff volumes from these data it is possible to achieve a high accuracy of prediction of the water level in the sewer pipes. The methods used for making these predictions are as follows.

1) Rainfall Prediction

There are meteorological radar units monitoring all parts of Metropolitan Tokyo to determine the rainfall volumes on a 250m grid. The rainfall observation data are sent also to the Shinozaki pumping station in real-time. Moreover, there are four telemeter stations for measuring rainfall in the catchment area. The rainfall observation data are transmitted to the Shinozaki pumping stations every minute. At the Station, rainfall forecasts are made using both the radar gauge and telemeter rain gauge measurement data as the rainfall forecast 30 - 45 minutes ahead.

2) Prediction of Water Inflow Volume into the Sewer Pipe

Based on the rainfall data described in 1), the runoff volume is calculated to predict the water inflow into the pipes.

3) Prediction of Water Level in the Sewer Pipes

Based on the sewer inflow prediction mentioned in 2), the hydraulic calculations are performed according to the pump operating rules to predict the water level in the sewer pipes. Operating rules established after verifying the simulation results targeting the rainfall patterns of the past.

On the basis of these calculation data, the operating data corresponding to the relevant conditions, such as number of pumps, start/stop time, etc, are output. For operation in real-time, the time required for starting/stoping the pumps and the pump delivery curve are taken into consideration during pump operation.

4. Hydraulic Model

4.1 Tools for Introducing the RTC System
Bureau of Sewerage in TMG has conducted research with a view to investigating and practically using the stormwater runoff volumes from the viewpoint of 1) flood prevention measures, 2) CSSIs, and 3) planning of sewer routes. The Public Works Research Institute (PWRI) of the Ministry of Construction (MOC, currently the Ministry of Land, Infrastructure and Transportation (MLIT)) uses mainly a procedure based on the rational formula and the modified RRL method (the Road Research Laboratory (RRL) Method developed in the United Kingdom). This procedure is an amendment of the estimation method for the effective stormwater volume and storage volume-flow curve.

For developing the RTC system configuration, it is necessary to determine the water level at any random location and the flow volume in a dynamic manner. To achieve this, the MOUSE software is used. This software has been specifically developed for resolving the problems of water pollution of the public water bodies as a result of wastewater overflow in wet weather and for resolving flood problems.

The main reasons for our selection of the MOUSE software are as follows.

1) It has a coordinating function for rivers and sewerage system.
2) It offers a greater level of reliability and stability than other software products for the complicated pipe route networks.
3) It is capable of handling a larger number of items for water quality analysis than other software products and can perform calculations in conjunction with water quality.
4) It has ample capacity for program additions, corrections and backup capability.
5) It is used to a large extent for RTC systems.

MOUSE is an integrated urban effluent and wastewater analysis software program capable of being used for calculating surface runoff and wastewater discharge to the sewer pipe, water quality and the transport of the sedimentation load.

4.2 Preparation of Hydraulic Model

In catchment areas in which only a short time of 10 to 30 minutes from the outbreak of rain to overflow runoff, the important conditions for achieving pump control in real-time are the time required for obtaining the measurement data, the stabilized solution in the hydraulic model, and the time required for the hydraulic calculations. It is thus necessary to obtain new information at least every 5 minutes. The time required for acquiring the measurement data is 0.5 - 1 minutes for the ground rainfall gauges and the water level in the pipes and 2.5 - 3 minutes for the radar rain gauges. As a result the limit time required for the hydraulic calculations and for supporting the decision-making process is around 1 minute.

In this context, we have performed simulations to determine the final model. These simulations were based on the actually measured rainfall volumes and water level to find out in what manner the calculation time varies in accordance with the...
number of target pipe routes and to determine whether the calculation values can reproduce the actual measurement data with reasonable accuracy.

To verify the hydrological phenomena associated with the development of the sewerage infrastructure and the expansion of the catchment area, we have checked the following four items for verification by using a model that had already been established model of sewer networks with diameters of 1500mm or more (Model A).

1. Collecting data such as the diameter, length, and ground elevation of the various pipes for detailed verification.
2. Verifying the accuracy of reproducing the hydraulic phenomena using a model (Preparation of 3 hydraulic models, having a pipe diameter of 1500mm or above, one of 1000mm or above and 800mm or above, respectively (Models A, B, and C).
3. Comparing the variation in the calculated water levels for each model and the time required for the calculations.
4. Determining the final hydraulic model and calculating the changes in water level.

The data used in the model, including pipe diameter, slope, overall length, and ground elevation are determined on the basis of the completion drawings and the Sewerage Mapping and Information System (SEMIS) developed by TMG in 1985.

Figure 4 shows a plan view of the three hydraulic models.

**Figure 4- Plan Views of the Hydraulic Models for the Catchment Area of the Shinozaki Pumping Station.**

**4.3 Model Verification**

It is necessary to check whether the hydraulic model that has been prepared is capable
of reproducing the actual phenomena in an appropriate manner. For this purpose, simulations have been run for the various rainfall patterns, and from the data the constants for the model that is capable of reproducing the actual phenomena have been determined on a test basis.

For the Shinozaki pumping station’s catchment area, water level observations had already been carried out in the past in preparation for efficient infrastructure development and a model for the trunk sewer using an indefinite flow was configured. We therefore verified the model by using the actual rainfall data and water levels measured at that time on the basis of model A prepared in 4.2.

For calibrating the catchment area of the Shinozaki pumping station, we first ran a simulation on the basis of model A for the five rainfall patterns presented in Table 2 which gives records of the water levels measured in the trunk sewers.

### Table 2 - Verified Rainfall Data

<table>
<thead>
<tr>
<th>Date (Service area, ha)</th>
<th>Nijuku</th>
<th>Hosoda</th>
<th>Koiwa</th>
<th>Shinozaki</th>
<th>Runoff rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Aug-85 (527.17ha)</td>
<td>46.0</td>
<td>63.0</td>
<td>71.0</td>
<td>62.0</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>11.0</td>
<td>15.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>06-Sep-85 (527.17ha)</td>
<td>20.0</td>
<td>15.0</td>
<td>7.0</td>
<td>4.0</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>13.0</td>
<td>4.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>06-Nov-85 (527.17ha)</td>
<td>32.0</td>
<td>32.0</td>
<td>36.0</td>
<td>37.0</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>11.0</td>
<td>12.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>08-Sep-91 (1991.85ha)</td>
<td>70.0</td>
<td>70.0</td>
<td>79.5</td>
<td>89.5</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>25.0</td>
<td>32.0</td>
<td>38.0</td>
<td></td>
</tr>
<tr>
<td>18-19-Sep-91 (1991.85ha)</td>
<td>214.0</td>
<td>191.0</td>
<td>200.0</td>
<td>222.0</td>
<td>Early stage: 0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Later stage: 0.88</td>
</tr>
</tbody>
</table>

The relevant parameters were adjusted, accordingly. Figure 5 shows examples of calculation results using the ultimate constants. It can be seen that the calculated water levels (solid line) are capable of reproducing the actual water levels (circle (o)).

For the three rainfall patterns covered by the study from August to October 2001, the models A, B, and C were verified by using the minute-by-minute water level data of 11 locations in the trunk sewer and the rainfall data at four locations. Figure 6 shows the results. The rainstorm patterns were those of August 22 (Typhoon: total rain volume: 59mm, hourly maximum: 22.5mm), of September 11 (Typhoon: total rain volume: 135mm, hourly maximum: 24.5mm) and of October 1 (Typhoon: total rain volume: 57mm, hourly maximum: 13.5mm). Evaluation of the three models in terms of the reproducibility of the measurement and calculation data on the basis of the correlation coefficient and the mean square error showed that, as can be seen in Table 3, there is no significant difference among models A, B, and C. As can be seen in Figure 7, however, model A has a somewhat excessive water level due to the fact that
the inflow area is concentrated at the upstream end of the trunk sewer.

With regard to the calculation processing time, however, it can be seen that when we take the calculation time for model A as 1.0, the hydrographic calculation time for the catchment area will be 1.1 for models B and C, and the hydraulic calculation time 1.5 for model B and 2.1 for model C. The calculation processing time for model C was around 8 seconds per hour simulation time, seeing that it took 335 seconds to process the calculation data about 43 hours to run the simulation.

We will use model C for examining the RTC rules since this model is capable of reproducing in detail the phenomena at the upstream end. However, model C takes more than double the time required for processing the calculation data in the case of model A. In view of the future extension of the functional capabilities, including the rain forecasts based on radar data and the decision-making support function, however, we decided to use model A for online use. This model provides only a small reduction in the operational requirements.

### Table 3 - Correlation between Measurement and Calculation Values

*(Example, Water level gauge No. 111)*

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient</td>
<td>0.88</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>Mean square error</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Figure 5 - Examples of Model Verification*
5. The Effect of Controlling CSO using RTC System

We have evaluated the reducing effect of frequency of CSO that can be achieved by increasing the height of the flow dividing weir in the bypass pipe and by using a higher water level than is used at present for starting and stopping the stormwater pumps at the Shinozaki pumping station which is located farthest downstream so as to store stormwater in the trunk sewer. Based on the rainfall data for the last twenty years, we have used the average number of rainfalls that occur in a year (76 rainfalls).
The limit to which stormwater can be stored has been taken as corresponding to a water level (pipe crest of the inflow sewer) 3m lower than the bottom of the pumping station’s sedimentation pond to allow for a safety factor for water permeation. Figure 8 shows the CSO-reducing effect with the RTC system, for each of the different rainfall patterns. The CSO-reducing effect achieved with the RTC system is as high as 54% for rainfalls with a total stormwater volume of 20mm or less, that is, a rainfall pattern accounting for half of the rainfalls that occur in a year. It can also be seen that rainfalls with a total stormwater volume of 30mm or less which account for 90% of all annual rainfalls, this CSO controlling effect is 36%.

The use of rainfall forecasting increases the accuracy of predicting the inflow volume into the pipe and the water level in the pipe. This offers greater flexibility in varying the pump-actuating water level in accordance with the scale of the rainfall. Let us assume a case in which rainfall prediction is properly implemented. We have carried out a calculation to test the extent to which CSO can be reduced by varying the pump-actuating water level in accordance with the rainfall intensity. The results are presented in Figure 9.

It has been found that the CSO-reducing effect achieved after introducing rainfall forecasting with the RTC system is much higher than without rainfall forecasting. With rainfall forecasting, the CSO reducing effect is 84% for rainfalls with a total

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**Figure 7 - Example of Longitudinal Section of Trunk Sewer Water Level**
(Rainfall on Sept. 11, 2001)
stormwater volume of 20mm or less which account for half of the rainfalls occurring in a year. It is 54% for rainfalls with a total stormwater volume of 30mm or less which account for 90% of the annual rainfalls. Thus compared with the effect before using rainfall forecasting with RTC system, it is possible to expect an improvement in CSO reduction effect by 30% and 18% respectively as a result of rainfall forecasting.

An assessment of the effect achieved with RTC system against the costs required
for CSSI on the system shows that the costs involved in the introduction of the system in the Shinozaki pumping station’s catchment area amounted to approximately US$3,846,153 (based on an exchange rate of 130 Yen/dollar). Thanks to the water-storage-pump operation made possible with RTC system, however, it is possible to store approximately 50,000 m$^3$ of stormwater as compared with the present pump-operating regime. The construction costs needed for this type of storage reservoir would be approximately US$1,538.5 per m$^3$ leading to total investment cost as US$76,925,000. It is clear that with the RTC system we can achieve the same effect at only a twentieth of the cost. If apart from the construction costs, we also include the costs for obtaining the land and the costs for measures to prevent inconvenience to the residents during the construction period, the effect of the RTC system, which can make use of the existing facilities as they are, becomes even more prominent.

6. Conclusion

In this study we have carried out a simulation to ascertain the effect that can be achieved by introducing the RTC system for the Shinozaki pumping station in Tokyo. This was chosen because its catchment area has a flat topography, and because the sewer system offers some water storage potential and also because pump operation is not complicated. We have compared the relative differences in the calculation data according to the number of pipes included in this study. As a result, it has been realized that a hydraulic model with a pipe route of 1500mm or more and approximately 200 nodes is capable of providing calculation results with a sufficient degree of accuracy on the basis of the control data from the RTC system. Furthermore, by storing stormwater in the pipe at the start of rainfall, it is possible to reduce CSO frequency by approximately 50% in case of a total rainfall volume of 20 mm or less. It has also been forecast that CSO can be reduced by approximately 80% by introducing rainfall forecasting.

This system was installed at the site in August 2001 and its trial operation has only just started. The task ahead will be to examine operating schedules for various rainfall patterns to upgrade the reliability and safety of the system. The fields that will need further studies are:
1) Examining the possibility of operational control by using radar rainfall data and runoff forecasts.
2) Examining ways of making the water quality model more sophisticated.
3) Examining the basic structure of the decision-making system to support operation.
4) Operational studies

From the operational viewpoint, the use of the RTC system will make it possible to accommodate even higher water levels in pipe than before. From the viewpoint of preventing inundation, it will be imperative that the system has to be seen as totally reliable by the operating staff, seeing that safety standards will be tightened to an ever-increasing extent. It will therefore be essential in the system configuration
process to establish the pump operating procedures through close investigation and consultation with the operating staff at the site. At present, we are gathering the necessary data for RTC system, including rainfall data and information about the water levels in the trunk sewers. The fusion of this variety of data with the know-how of the operating staff will eventually lead to a highly reliable system.

Based on the operational evaluation of the RTC system that has been introduced, there are further plans to consider the use of the system also in other catchment areas. We will devote the full thrust of our efforts to achieving the most important tasks of preventing inundation and improving the combined sewer without fail.

References
2) Users’ Manual of Runoff Analysis Models, Japan Institute of Wastewater Engineering Technology, March 1999