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Availability of CSO Control and Flood Control of Real-Time Control System in Urban Pumping Station

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ABSTRACT

In 2004, Bureau of Tokyo Sewerage has installed real-time control system (RTC system) to Umeda pumping station. RTC system in Umeda pumping station differs from the one in Shinozaki pumping station, which installed RTC system first of all plants of Bureau of Tokyo Sewerage in that its equipments are not only CSO control but also flood control by operating pumps according to the inflow increase. The purpose of this thesis is to evaluate the RTC system in Umeda pumping station by the field test.

The field test, which was done from 2005 to 2006, showed that the RTC system reduced 19.2 % of discharged stormwater, 27.3 % of BOD, 27.6 % of COD, and 24.3 % of SS compared to before. And RTC system operates pumps precisely to match the downpour, therefore there are no disasters such as inundation around the basin of Umeda pumping station.

As shown above, we confirmed the availability of RTC system.

KEYWORDS: Real-Time Control System, RTC, CSO control, flood control, MOUSE

INTRODUCTION

The 23 special ward area is the "central" area of Tokyo Metropolis. Separated sewer system is superior to the combined sewer system in the point of the preservation of water quality, but 82 % of Sewer system inside 23 wards is maintained by combined sewer system, and the rest is by separated sewer system.

Combined sewer system has the problem which causes the contamination in public water area. Furthermore, the downpour in local area caused by the result of urbanization and heat island frequently occurs these days. Therefore, we should take preventive measures against inundation more than before.

To solve these problems, we must expand hardware system of sewer system, such as stormwater storage reservoir and reconstructing the present combined sewer system to separated sewer system. However, these measures are not readily achievable and bring about high cost-increase. Therefore, in 2001, Tokyo metropolitan government established “Sewerage Plan 2001” and took measures to combined sewer system. And it also established “Quick Plan for combined sewer system” as short-term program for improvement of combined sewer system. In this “quick plan”, in purpose of CSO control and flood control we installed Real-Time Control System (RTC System), which makes the best use of capacity of present pumping station without stormwater storage reservoir.

General RTC system operates pumps by storing stormwater by using the capacity of inflow canal and it keeps the water level high, so it has a risk of inundation around grit chamber. But RTC system in Umeda enables not only CSO control but also flood control by operating stormwater pumps according to the inflow increase. The purpose of this thesis is to evaluate the RTC system in Umeda pumping station by the field test.

Selecting pumping station for installing RTC system

As installing RTC system to present pumping station, we selected Umeda pumping station for the condition as follows. Under these conditions, installing RTC system to Umeda pumping station was expected to have more effect in the point of CSO control than other pumping stations.

1. inflow canal has large capacity of water reservoir (large in diameter)
2. inflow canal is almost straight (the estimated amount of inflow has less error)
3. not remote-controlled system

The Outline of RTC System in Umeda Pumping Station

Figure 1 shows the outline of RTC system in Umeda pumping station. This system estimates the inflow to the pumping station by using the precipitation data obtained by the ground gauge placed in this pumping station, the inflow canal level data obtained by the optical water level gauge which uses optical fiber placed inside the inflow canal, and the rainfall information system (Tokyo Amesh) which can grasp rainfall inside Tokyo by 250 m square mesh. Furthermore, in this estimation process, the system takes the starting time of pumps and the Pump-characteristic curve into consideration and it uses Sewerage Mapping and Information System as sewer network data. According to the estimation it controls CSO by using storage capacity of the inflow canal.

As mentioned above, this RTC System estimates the inflow by using the precipitation data. Therefore, when heavy rain occurs, it operates stormwater pumps in order to avoid the inundation. Thus, this RTC System enables not only CSO control but also flood control by operating pumps according to the inflow increase.

Figure 2 shows the components of RTC system in Umeda pumping station. RTC system consists of RTC data processing unit for real-time condition analysis, RTC data base unit, DIMS server

(Dynamic Integrate Monitoring System), DIMS terminal.
Data processing unit forecasts 10 minutes ahead condition by hydraulic analysis model and data base unit save the data from data processing unit and other interfaces. DIMS server intermediates between RTC system and external units, and we can know the present condition by DIMS terminal.
PIO unit receives the inflow canal water level data through fiber placed inside the inflow canal and sends it to the DIMS server with other monitoring data of Umeda pumping station. However, Amesh Data Converter sends precipitation data from the rainfall information system directly to DIMS server. RTC systems send the on/off command of pumps and generators through PIO unit.

Outline of Umeda pumping station

There are 3 trunk sewers to Umeda pumping station. Umeda trunk sewer and Hokima trunk sewer are connected to main building and Aoi Stormwater trunk sewer is connected to Aoi building. Aoi Stormwater trunk sewer is constructed by separated sewer system, so RTC system in Umeda pumping station does not control Aoi building. Table 1 shows the details of sanitary district of Umeda pumping station.

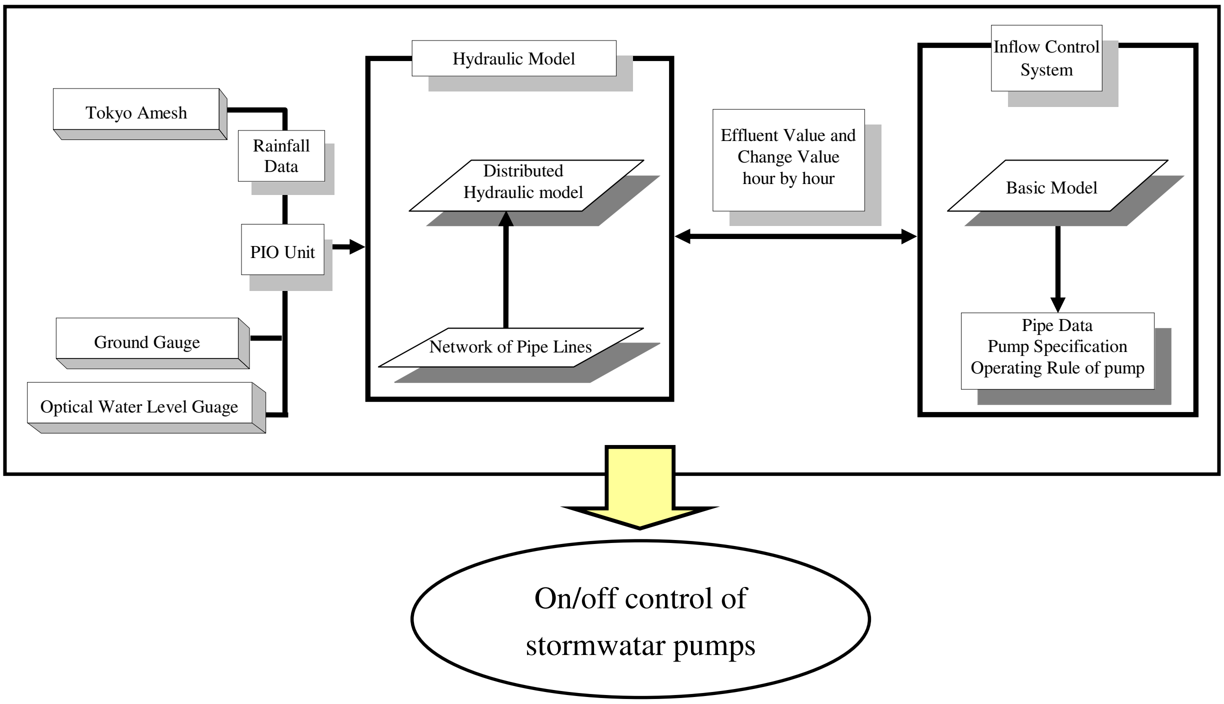


Figure 1. Outline of RTC System

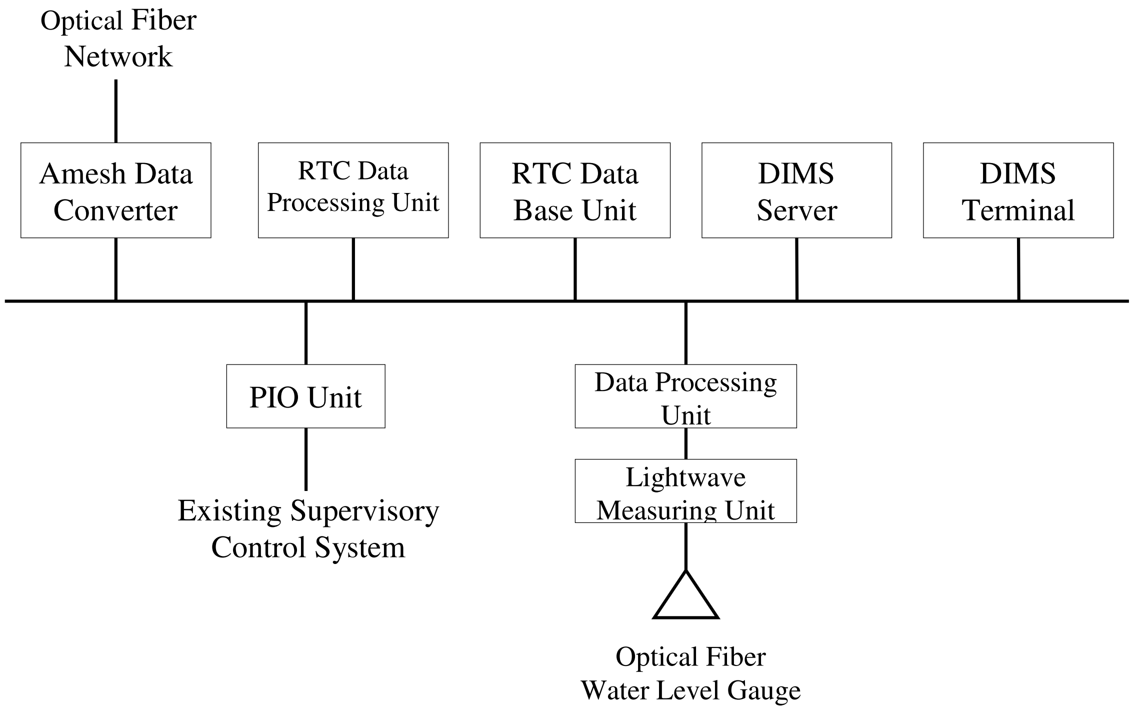


Figure 2. Components of RTC System in Umeda pumping station

Table 1 Details of sanitary district of Umeda pumping station (main building)

item			Data
Design Drainage Area	Sanitary Sewage (ha)		539.20
	Storm Sewage (ha)		1,113.1
Design Drainage Volume	Sanitary Sewage (m^3/s)	Dry Weather	1.778
		Wet Weather	4.704
	Storm Sewage (m^3/s)		102.420
Honkan Trunk Sewer	Umeda Trunk Sewer (mm)		φ5,750
	Hokima Trunk Sewer (mm)		φ4,500

6 Stormwater Pumps by Electric (7 m^3/s)

3 Stormwater Pumps by Diesel Engine (15 m^3/s)

Installing RTC system to Umeda pumping station

We had done prior investigation in 2003 and began to install RTC system in 2004. After that, we started experimental operation in 2005. And in 2005 we built up it by increasing the number of water level gauges in trunk sewer and from 10th May 2006, we put RTC System to practical use. Since then, RTC system keeps nonstop operation.

Table 2. Installing RTC system to Umeda pumping station

Year	Outline	Contents
2003	prior investigation	Drainage Basin Survey Hydraulic Modelling
2004	Installing	Set Up RTC System Set Up Water Level Gauges in Trunk Sewer (Total 3 Umeda Trunk Sewer 2, Kouya Trunk Sewer 1)
2005	Practical Use Start Full Use Start	Evaluation of CSO Control (13 case of rainfall from August to March) Increasing the number of Water Level Gauges (Hokima, Nishiarai, Motoki Trunk Sewer 1 for each) Exchanging Diesel Engine Stormwater Pump Full Speed Stand by Pump Starting Non-Stop Operation
2006	Full Use	Evaluation of CSO Control (21 case of Rainfall from April to October)

CSO control and flood control

General RTC system operates pumps by storing stormwater by using the capacity of inflow canal and it keeps the water level high. This operation has a risk of inundation around grit chamber. This is the main problem of the RTC system. As expected, We had faced this problem in installing RTC system to Umeda pumping station.

We are in charge of the speedy removal of rainwater from land surface to public water bodies by stormwater pumps. Therefore, operators are required to operate stormwater pumps to avoid inundation in his instant and right judgement. CSO control and flood control are contrary to each other, so it had not been tried long time by using RTC system.

Prior investigation in 2003 reports that in case rainfall intensity is under 7mm/h and total amount of rain is under 25mm, RTC system can operate pumps precisely. But as a matter of course, during the rain, we cannot know total amount of rain. And if sudden change of rainfall intensity happens, operators should change RTC system to manual operation and operate stormwater pumps promptly. If we would install such RTC system to pumping stations, it could not be used actually.

Therefore, RTC System in umeda pumping station estimates the inflow by using the precipitation data and operates stormwater pumps according to amount of inflow in estimation. Thus, this RTC System enables not only CSO control but also flood control by operating pumps according to the inflow increase without manual operation.

How RTC System operates pumps

RTC system receive the measuring data such as precipitation data and water level data in some points and the number of operating pumps in real time and estimate the amount of inflow to grit chamber and water level in inflow canal by using “MOUSE” which is made by DHI. “MOUSE” is often used in simulating the inflow mainly in USA and some countries. General RTC system uses it and our former RTC system in Shinozaki pumping station uses “MOUSE”. For that reason, we adapt “MOUSE” to Umeda pumping station. The system control pumps according to the estimation by “MOUSE”.

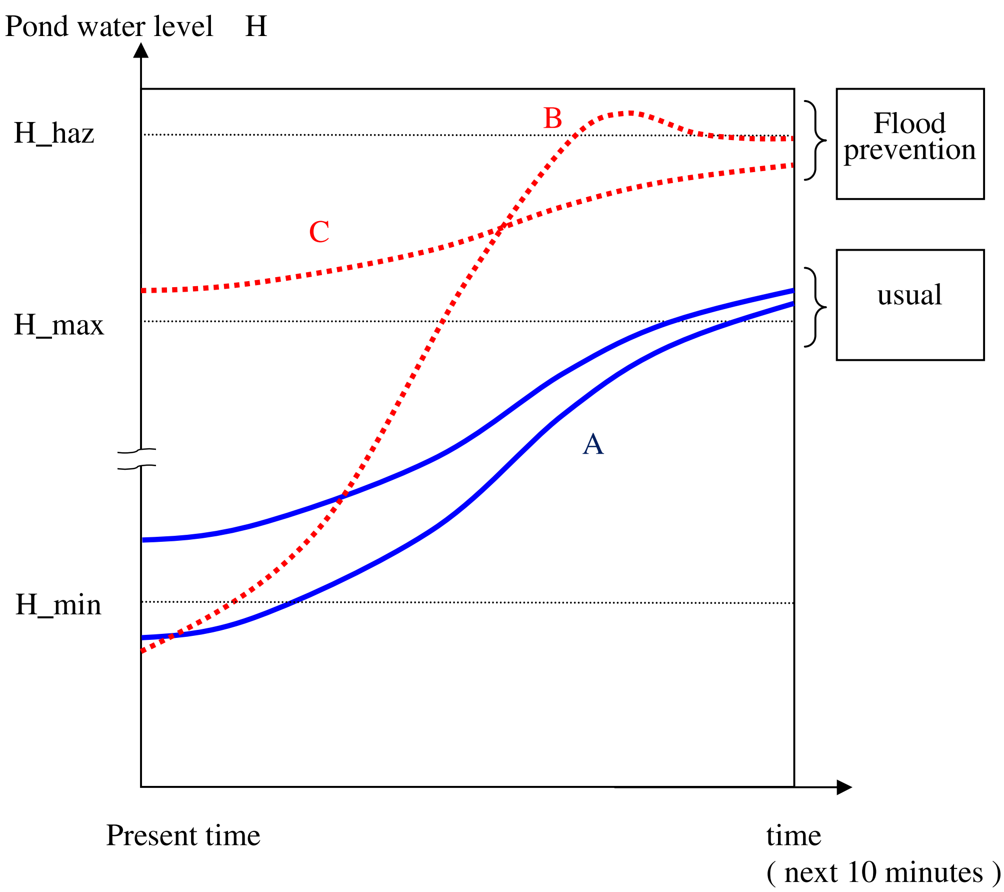
The judge of the on/off control of pumps occurs every 1 minute, and the system also expect 10 minutes ahead in this 1 minute cycle. In case of downpour, downpour causes immediate rush-in to pumping station and speedy rise of water level in inflow canal. Preparing for downpour, RTC system operates DE Full speed Stand by stormwater pumps before rush-in by judging precipitation data.

On/off control of stormwatar pumps

Pond water level and 2 modes

We define H_min, H_Max, H_haz for controlling Pond water level (cf. figure 3).

And there are 2 modes in this control system according to the pond water level in estimation. One is “usual mode” and the other is “flood prevention mode”. Figure 3 shows estimation of pond water level from the present to 10 minutes ahead.



If pond water level beyond H_haz,Umeda pumping station is in danger of inundation.
We should keep pond water level between H_min and H_max for safety operation.

Figure 3. water level and mode

The system controls only sewer pumps in usual mode. But in flood prevention mode, it controls sewer pumps and stormwater pumps. Figure 3 shows how these two modes behavior. X axis shows the time, and Y axis shows the pond water level.

In usual mode (line A), the pond water level is below H_max at the estimation time, and it prospects the pond water level will be below H_haz in next 10 minutes. Then it decides there is bare possibility of inundation and operates sewer pumps only.

On the other hand, in flood prevention mode (line B, C) the system prospects the pond water level will be above H_haz in next 10 minutes (line B). The pond water level is above H_max at the estimation time (line C). Then the system judges there will be high possibility of inundation and operates stormwater pumps according to the inflow estimation.

In flood prevention mode, the system tries to keep pond water level between H_min and H_max by judging on/off control of pumps in 10 minutes ahead in 1 minute cycle.

We calculate amount of water in need of pumping as shown below. T is the constant of revision.

Maximum amount = amount of inflow in estimation
+ (present storage amount – amount of water in H_min level)/T …(A)
Variable value 1
Minimum amount = amount of inflow in estimation
+ (present storage amount – amount of water in H_max level)/T …(B)
Variable value 2
T: 1800s
amount of water in H_min level: 6,500m^3
amount of water in H_max level: 34,000 m^3

In case the amount of pumped water equals to the amount of inflow in estimation, pond water level keeps the present condition. So while pond water level keeps between H_max and H_min, the system keeps the present operation.
In case the present pond water level is H_min, Maximum amount (shown in equation (A)) will be amount of inflow in estimation. Minimum amount (shown in equation (B)) will be below amount of inflow in estimation.
On the contrary, in case the present pond water level is H_max, Maximum amount (shown in equation (A)) will be more than amount of inflow in estimation. Minimum amount (shown in equation (B)) will be amount of inflow in estimation.
In short, Maximum amount and Minimum amount are based on amount of inflow in estimation and affected by the difference between present storage amount and amount of water in H_min level or amount of water in H_max level(Variable value 1, 2). Because the larger constant of revision T gets the smaller Variable value 1, 2 gets, the response to the amount of inflow will be slow. And Because the smaller constant of revision T gets the larger Variable value 1, 2 gets, the response to the amount of inflow will be fast. T which relates to the intensity of revision is set as 1800 after some trial and error. And amount of water in H_min level and amount of water in H_max contain capacity of grit chambers, pond and trunk sewer.

On/off control of stormwater pumps

RTC system judges on/off control of stormwater pumps as shown below.

Case 1: amount of pumped water at present < Minimum amount
The system operates additional pumps.

Case 2: amount of pumped water at present > Maximum amount
The system stops one of running pumps.

Case 3: Minimum amount < amount of pumped water at present < Maximum amount The system keeps the present operation.

RTC system operates pumps considering the start time and stop time. And in case the number of running pumps increases, it operates generators if needed.

Method of Evaluation of CSO control

We evaluate the RTC system's effect for CSO control by the method shown in Figure 4.

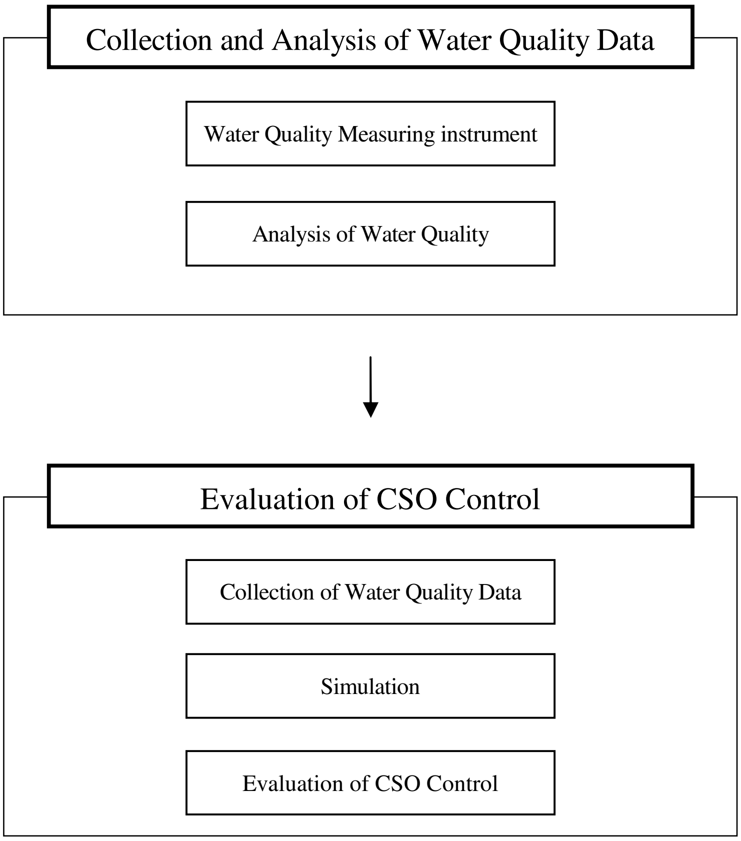


Figure 4. Evaluation method of CSO control

Analysis of pumped water quality

We set up automatic water-quality measurement instruments in grit chamber in Umeda pumping station and evaluate RTC on a rainy day. By Wastewater examination method, we analyzed concentration of BOD, COD (COD_{MN}) and SS of inflowing water.

At the beginning of the rain, there is the possibility of sudden changes of water quality of inflowing water. So we set measuring interval as shown below. RTC system judges the end of the rain at TP -11.7m and stops sampling. Water sampling was done from August 2005 to October 2006.

0-1 hours after first sampling every 5 minutes
1-2 hours after first sampling every 10 minutes
2-3 hours after first sampling every 20 minutes
3-4 hours after first sampling every 30 minutes

Evaluation of CSO control

There are two methods to operate stormwater pumps. One is by pond water level control at grit chamber and the other is by RTC system. It is impossible to compare them by field test at the same time, so we evaluate them by simulating the one which is not operating at the same condition. By multiplying BOD, COD, SS concentrations with the total amount of discharged stormwater, we calculate total amount of contamination load and relative improvement level between Water level control and RTC system.

Results

Effect for CSO Control

During the practical use rainfall occurs 34 times. The amount of discharged stormwater and total amount of contamination load are shown in Table 3. In these 34 times, pond water level control operated at 17 times and RTC system operated at 17 times.

The result was that RTC system reduced 19.2 % of discharged stormwater, 27.3 % of BOD load, 27.6 % of COD load and 24.3 % load of SS load compared with pond water level control system (Table 3).

Table 3. Effect of CSO Control by RTC System

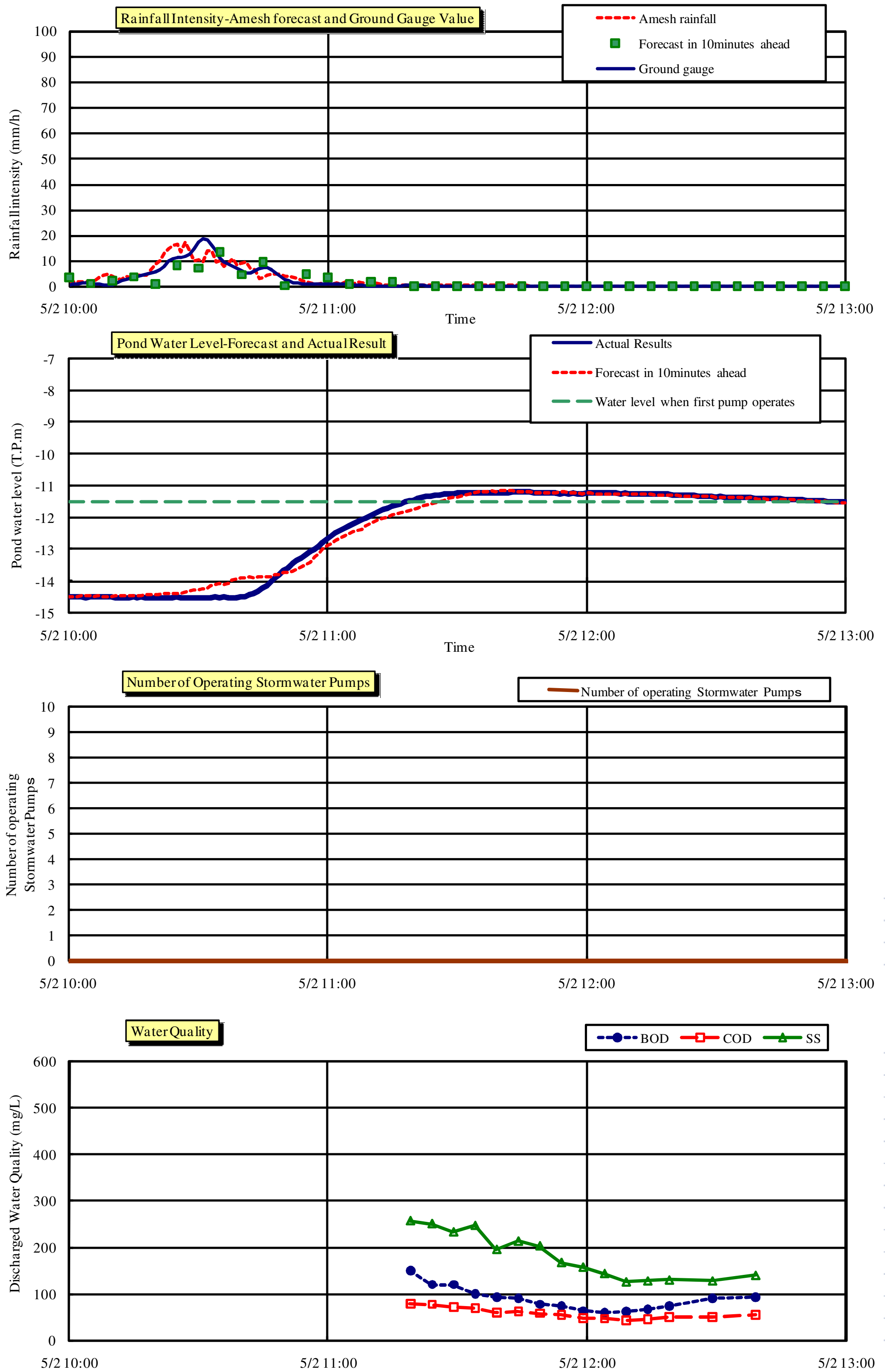
Evaluation item	Pond Water level control system (A)	RTC System (B)	Amount of reduction by RTC System (C)= (A)– (B)	Relative improvement level (%) (D)=(C)/(A)×100
discharged stormwater (m^3)	2,706,464	2,186,043	520,421	19.2
BOD load (kg)	135,026	98,202	36,824	27.3
COD load (kg)	89,161	64,586	24,575	27.6
SS load (kg)	303,407	229,599	73,808	24.3

Reduction of storm water discharge

RTC system control stormwater pumps by using storage capacity of inflow canal, RTC System operates few stormwater pumps compared to pond water level control. So amount of discharged stormwater decreases in moderate rain. In 8 cases of rainfall out of 34, RTC System operates only sewer pump. For example, we show how RTC System operates May 2nd, 2006 (Figure 5). At that time, total amount of rain was 5.5mm and maximum rainfall intensity was 5.0mm/h. Figure 5 shows that though pond water level was beyond TP -11.5m at 11:18 pm, RTC system did not operate stormwater pumps by judging rainfall information.

Like this, in moderate rain RTC system operates few stormwater pumps and amount of discharged stormwater decreases.

May 2nd, 2006



	BOD(mg/L)	COD(mg/L)	SS(mg/L)	FTU
Maximum	150	79	258	368
Minimum	59	42	126	222
Average	89	57	182	276

T.P.-10.0m means 10.0m below Average Sea Level in Tokyo Bay.

Figure 5. Driving Record of RTC System (May 2nd, 2006)

Decreasing First Flush (high contaminated water)

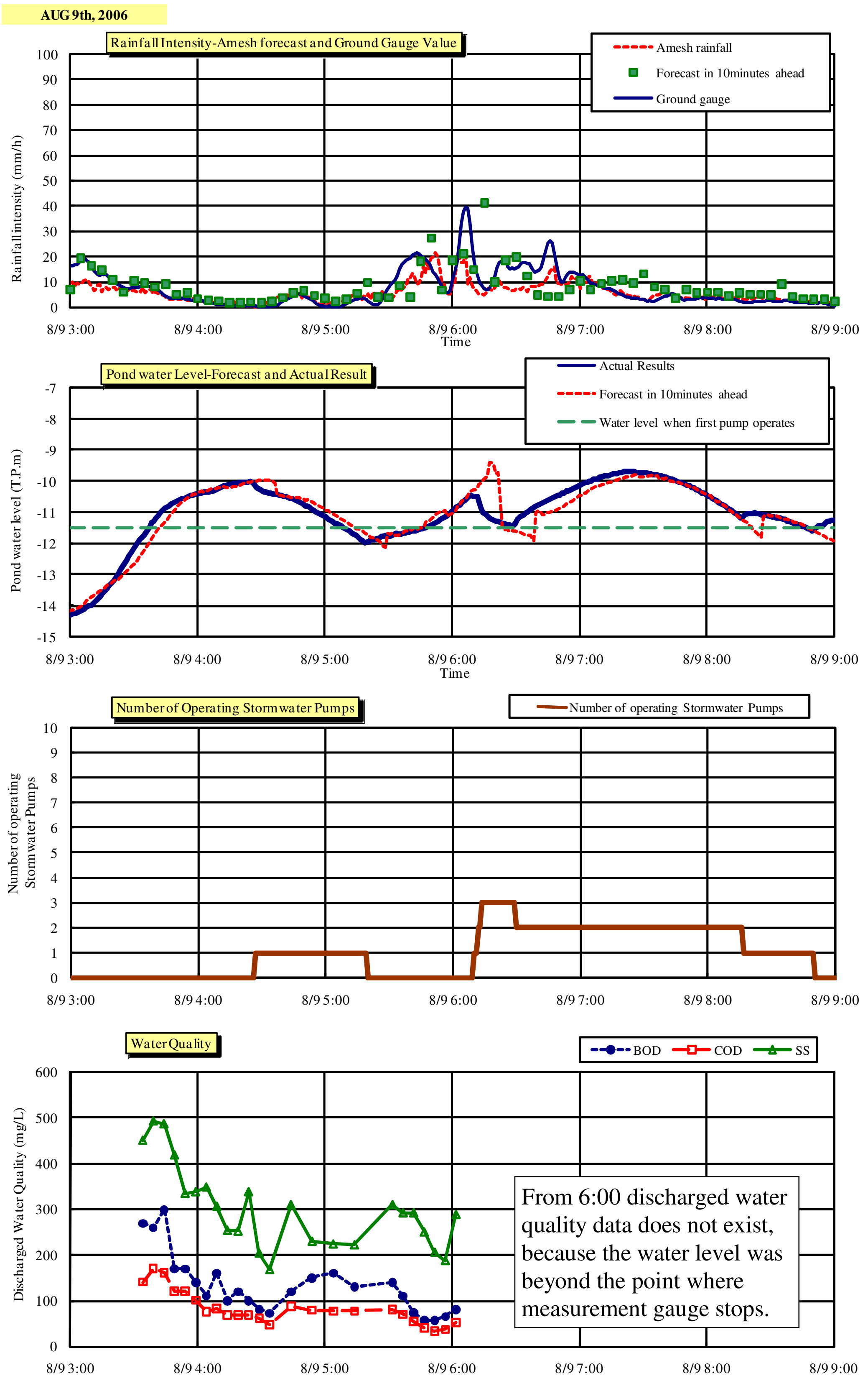
RTC system reduced 19.2 % of discharged water. But when it comes to BOD load and COD load, RTC system reduced 27.3 % and 27.6 % more than that of discharged water. This is because even though RTC system operates stormwater pumps, it can delay the starting time of them by using storage capacity of inflow canal and send it to waste water treatment plant by sewer pumps. So it can dilute first flush and decrease total amount of contamination load.

For example, we show how RTC System operates Aug. 9th, 2006 (Figure 6). At that time, total amount of rain was 45.0mm and maximum rainfall intensity was 16.0mm/h.

Pond water level control system was set to start operating stormwater pumps when pond water level was beyond TP -11.5m. So if conventional system had controlled the pumping station then, it would have started operating stormwater pumps at 3:38am. But in reality RTC System started operating stormwater pumps at 4:25am(Table 4). These data shows RTC System has good effect in the case of operating stormwater pumps in addition to the case of moderate rain by delaying starting time of stormwater pumps.

Table 4. Water Quality (Aug. 9th, 2006)

item	3:38	4:25
BOD (mg/L)	260	100
COD (mg/L)	170	69
SS (mg/L)	492	338



	BOD(mg/L)	COD(mg/L)	SS(mg/L)	FTU
Maximum	300	170	492	489
Minimum	56	33	168	120
Average	133	82	300	256

Figure 6. Driving Record of RTC System (Aug. 9th, 2006)

Operating pumps considering the rain fall condition

RTC system changes its mode to "Flood prevention mode" and operates stormwater pumps when it infers the danger of inundation. Figure 6 shows an example of this operation. From 6:00 am, rain had got heavier to 40mm/h and according to the rainfall intencity it operates stormwater pumps. At first it did not operate stormwater pumps, but a few minutes later it operates 3 stormwater pumps and later 2 stormwater pumps.

AUG. 4th, 2008 (this day is not included in 34 examples), downpour happened and rainfall intensity rose to 53.0mm/h and total amount was 69.5 mm. Figure 7 shows the example of this operation. 5 electric stormwater pumps and 2 Diesel Engine stormwater pumps had operated but it had no trouble such as inundation around grit chamber. RTC system had established its trust in the case of 50 mm/h rain.

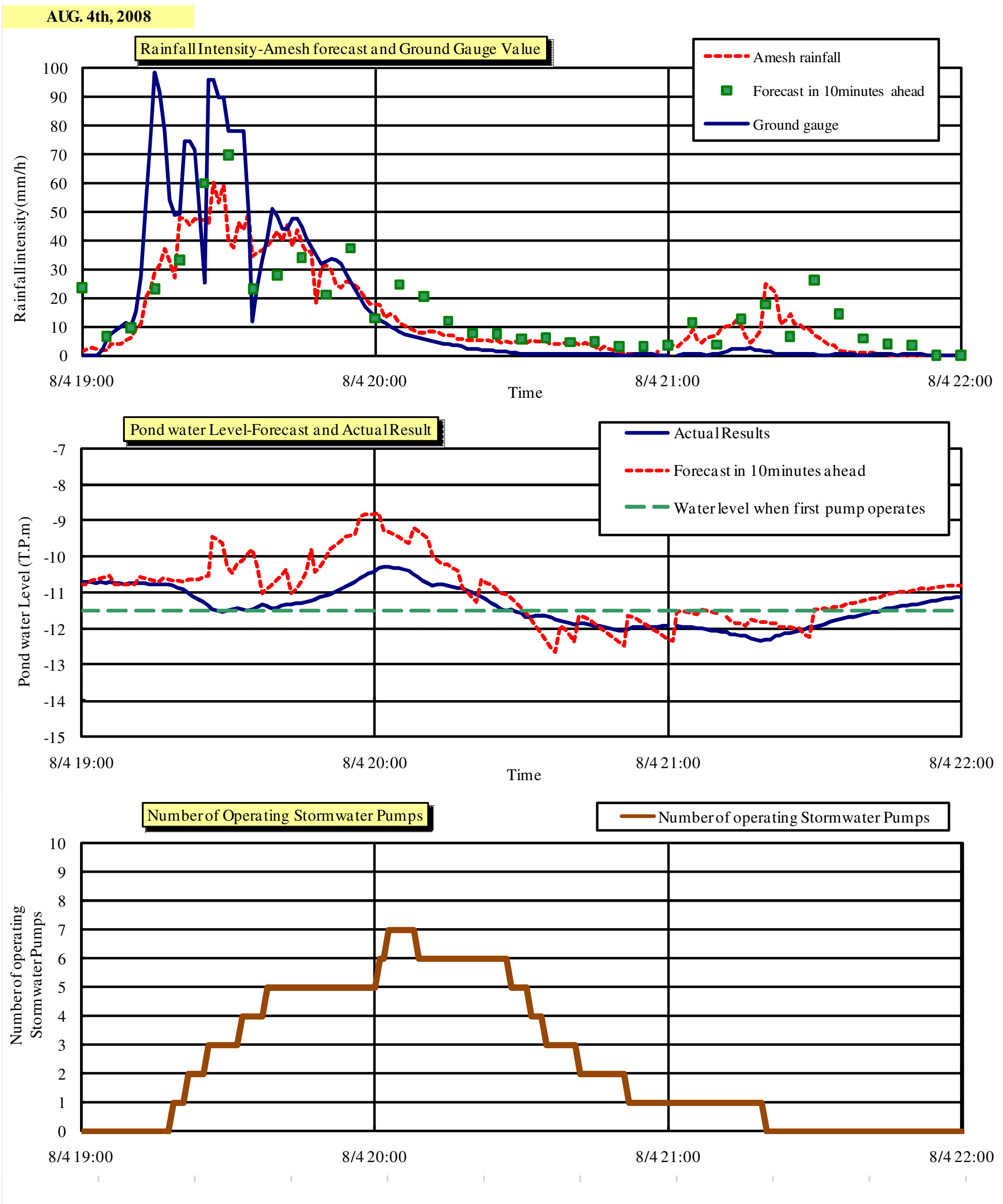


Figure 7. Driving Record of RTC System (Aug. 4th, 2008)

Relation between, total amount of rain rainfall intensity and CSO control

About sampling data obtained by 34 cases of rainfall, figure 8 shows the relation between total amount of rain and BOD relative improvement level. And figure 9 shows the relation between rainfall intensity. and BOD relative improvement level. From figure 8 and 9, if total amount of rain is small and rainfall intensity is weak, BOD relative improvement level had decreased. And if total amount of rain is large and rainfall intensity is heavy, BOD relative improvement level had decreased. This is because in moderate rain RTC system control pumps by using storage capacity of inflow canal rain and operates few stormwater pumps compared to before. And in downpour, it operates stormwater pumps for the risk of inundation.

Rainfall intensity has more relation to BOD relative improvement level compared to total amount of rain. This is because RTC system estimates the amount of inflow by using the amount of rainfall in next 10 minutes from precipitation forecasting system. And in case of heavy rain, RTC system controls pumps by using storage capacity of inflow canal and does not operates stormwater pumps if it is expected to stop in short time. So it can decrease operating time of stormwater pumps and the amount of discharged water.

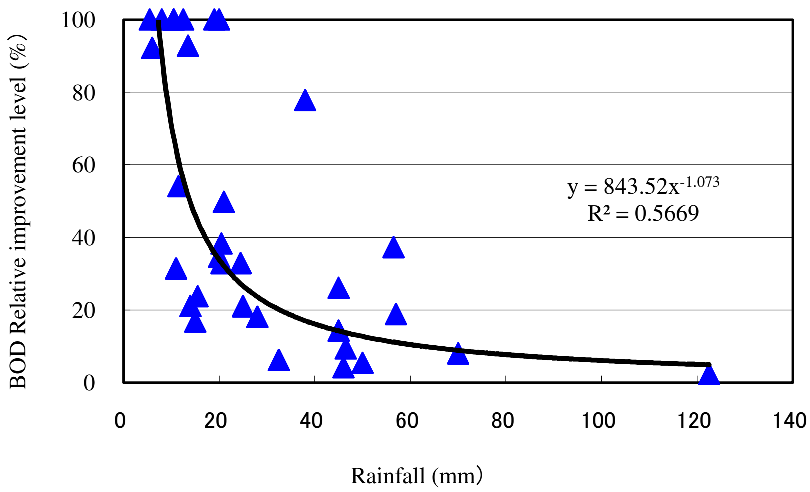


Figure 8. Total amount of rain and BOD load Relative improvement level

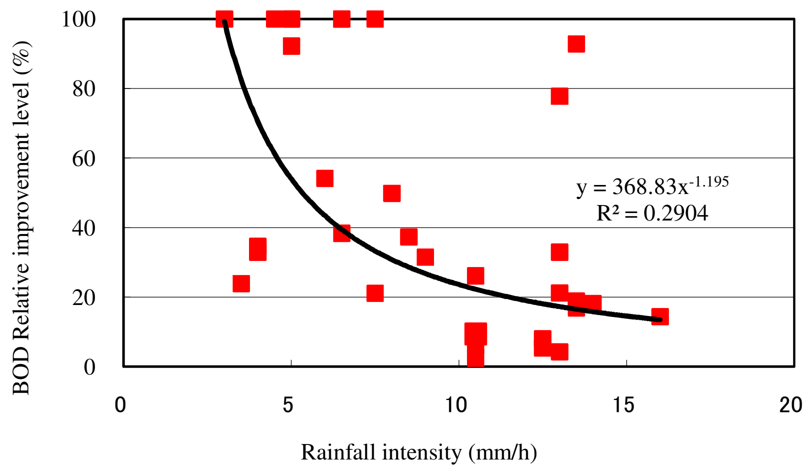


Figure 9. Rainfall intensity and BOD load Relative improvement level

Apply RTC system to Waste Water Treatment Plant

Even if RTC system in Umeda pumping station reduced the amount of discharged water by sending it to Kosuge Waste Water Treatment Plant (WWTP), it is no worth if the amount of discharged water increases in Kosuge WWTP.

In 8 cases (7 days) of rainfall out of 34, RTC system operates only sewer pumps so we researched Kosuge WWTP's operation data. Table 5 shows precipitation data of these 7 days. Total amount of discharged stormwater in Kosuge WWTP in SEP. 11st, 2005 is 35,250m^3. At this day the rain in Kosuge WWTP was relatively heavy (rainfall intensity 10.5 mm/h and total amount 14.5 mm) and it causes discharging water in Kosuge WWTP. Figure 10 shows the precipitation data around Kosuge WWTP from Tokyo Amesh. It shows that it rains heavier around Kosuge WWTP than Umeda pumping station.

All these 7 days except for SEP. 11st, 2005, Kosuge WWTP did not discharge stormwater, so stormwater sent from Umeda pumping station to Kosuge WWTP was treated. The distance between Umeda pumping station and Kosuge WWTP is 3.0 km and condition of the rainfall and inflow is not the same so we can say wastewater sent from Umeda pumping station will be treated if rainfall intensity around Kosuge is below 7.5mm/h. This is because WWTP is larger in its capacity than pumping station, so it can absorb the increasing amount of inflow by RTC system.

As mentioned above, RTC system has effect for CSO control considering both Umeda pumping station and Kosuge WWTP.

Table 5. Precipitation data of the 8 cases (7 days) rainfall

Date	Umeda pumping station			Kosuge WWTP		
	Total amount of rain (mm)	Rainfall intensity (mm/h)	Discharged stormwater (m^3)	Total amount of rain (mm)	Rainfall intensity (mm/h)	Discharged stormwater (m^3)
SEP. 6th, 2005	12.5	5.0	0	7.5	2.0	0
SEP. 11st, 2005	8.0	6.5	0	14.5	10.5	35,250
SEP. 25th, 2005	10.5	6.5	0	11.0	7.5	0
OCT. 10th, 2005	19.0	7.5	0	20.5	7.0	0
NOV. 6th, 2005	15.5	4.5	0	17.0	4.0	0
MAY 2nd, 2006	5.5	5.0	0	6.0	5.5	0
JUN. 15th, 2006	10.5	3.0	0	14.0	4.5	0

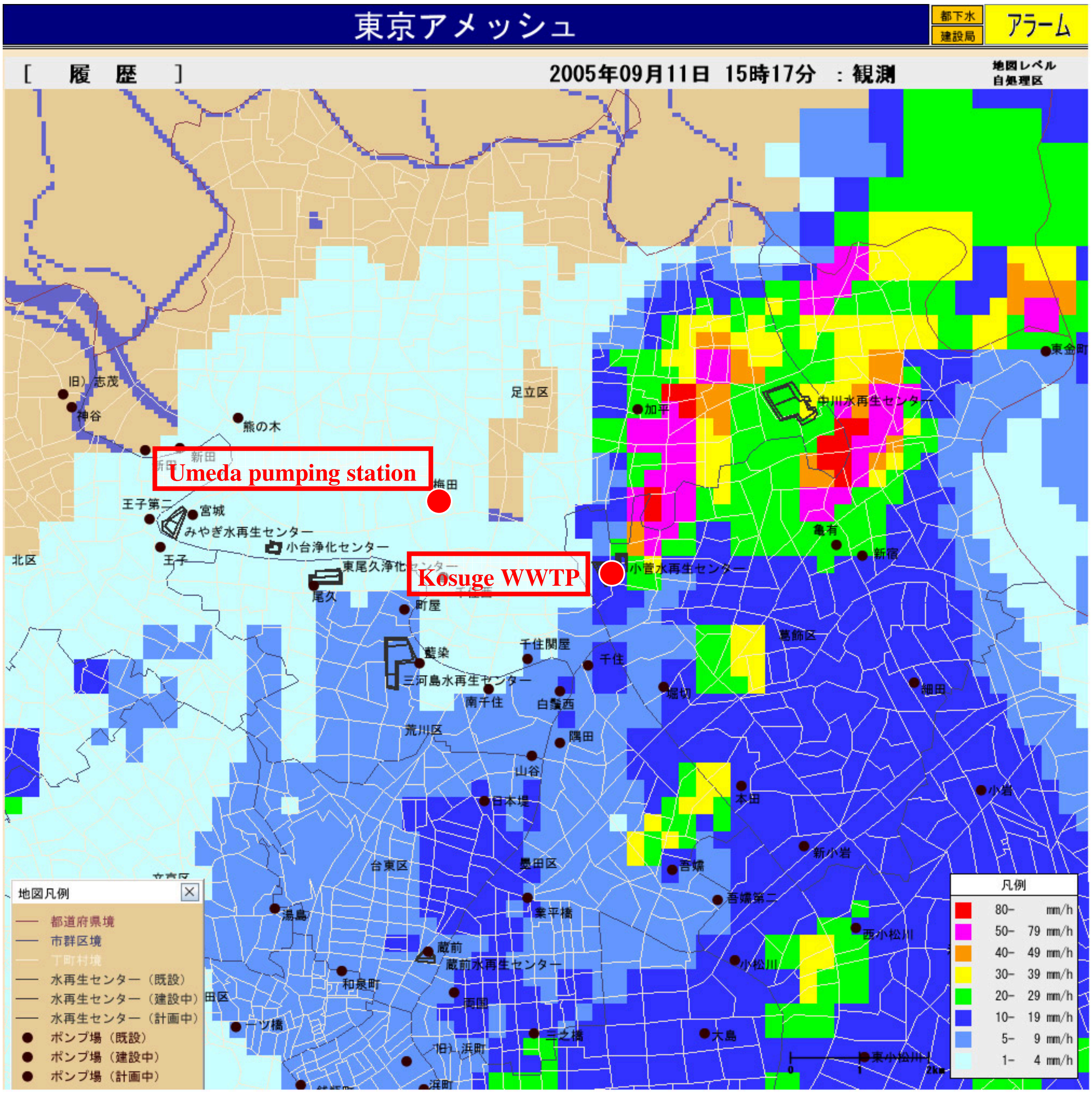


Figure 10. Tokyo Amesh(SEP. 11st, 2005)

Conclusion

- Practical use showed that the RTC System reduced 19.2 % of discharged stormwater, 27.3 % of BOD load, 27.6 % of COD load and 24.3 % load of SS load compared to pond water level control.
- Even if RTC system operates stormwater pumps in case of heavy rain, we can decrease total amount of contamination load by diluting first flush and sending it to WWTP.
- In the case of moderate rain, by using storage capacity of inflow canal, RTC System operates few stormwater pumps compared to pond water level control and by decreasing the amount of discharged water, it has the effect for CSO control.
- RTC System operates pumps precisely to the downpour, so there are no disasters such as inundation around the grit chamber of Umeda pumping station. Therefore we appreciate RTC System as preventive measures to inundation.
- BOD load relates to the rainfall intensity rather than total amount of rainfall, so we can say Tokyo Amesh data has much to do with the estimation of inflow.
- Though RTC operates stormwater pumps and sends it from pumping station to WWTP, it can absorb the increasing amount of inflow by RTC system.

Future Work

Some problems had taken place since we put RTC System to practical use.

- We cannot know the process of hydraulic accounting in display, so we cannot know how RTC system judges its operation.
- 100 mm/h rain has not occurred around Umeda pumping station, so we should verify how RTC system operates.
- In case of downpour RTC system directs operators to shut inflow gate in the last resort. Until the present, this case has not happened yet, so we cannot evaluate this function. If capacity of pumps and civil structure are modified, we should correct software in order to improve accuracy. We should keep trying to solve these problems.

As mentioned before, we should consider these conditions to install RTC system.

1. inflow canal has large capacity of water reservoir (large in diameter)
2. inflow canal is almost straight (the estimated amount of inflow has less error)
3. not remote-controlled system

To apply this system to other basins as a method of CSO control, we should consider costs, accuracy, risk of inundation and intelligibility for operators to handle.