Combined Sewer System Improvement in Osaka City

—Wet Weather Activated Sludge Process—

大阪市における合流式下水道の改善

—雨天時活性汚泥プロセス—

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Osaka City Government, Japan

大阪市都市環境局　松本広司

COMBINED SEWER SYSTEM IMPROVEMENT IN OSAKA CITY
- WET WEATHER ACTIVATED SLUDGE PROCESS -

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ABSTRACT

The sewered ratio in Osaka City is almost 100% in population and the combined sewers have been adopted in approximately 97% of the sewered area. However, the combined system presents pollution of public water bodies, because untreated sewage is discharged from combined sewer overflow outfalls and pumping stations together with stormwater when sewage flow exceeds the capacity of sewer systems during wet weather. Accordingly, improvement of the combined sewer system is one of the most important and pressing issues to be addressed for the city. Osaka City set a phased target to implement its combined sewer system improvement program, particularly the middle term target was set as reducing discharged pollutant loads from the combined sewer system to the equivalent level of a separate sewer system. To meet this target, we have conducted various studies and developed wet weather activated sludge Method as a unique technology for continuous treatment of wet weather sewage. From the results of effluent quality surveys, it was verified that discharged pollutant load can be reduced by average 73% in SS and 61% in BOD with wet weather activated sludge process compared to the conventional process. Since this method can exert considerable effects without significant changes of existing facilities, Osaka City is promoting application of this method to all sewage treatment plants as well as construction of stormwater reservoirs.

KEYWORDS

Combined Sewer System, Water Pollution, Discharged Pollutant Load, Wet Weather Activated Sludge Process, Stormwater Reservoir

INTRODUCTION

Osaka City is the largest city in western Japan with the resident population of 2.63 million (daytime population: 3.6 million) and an area of 220 km^2. It is located on the estuary of the Yodo River and the Yamato River, therefore, the geography of Osaka is mostly flat and low, except for some small areas such as the Uemachi Plateau extending in the north-south direction. Accordingly, stormwater drainage has long been an urgent issue to be addressed. Also, epidemics of infectious diseases that posed public health risks in 19^{th} century have facilitated the improvement of wastewater drainage in a possible short time.

Under such circumstances, Osaka City adopted combined sewer systems, because it could be constructed with lower costs and it had an advantage of easiness in installation in the area where there were many narrow roads at that time. With continuous efforts in constructing combined sewer systems, the sewered ratio in Osaka City has reached to almost 100% in population and the sewage system has greatly contributed to the water quality improvement in the public water bodies. Currently, combined sewers have been constructed in about 97% of the sewered area, as shown in Fig. 1.

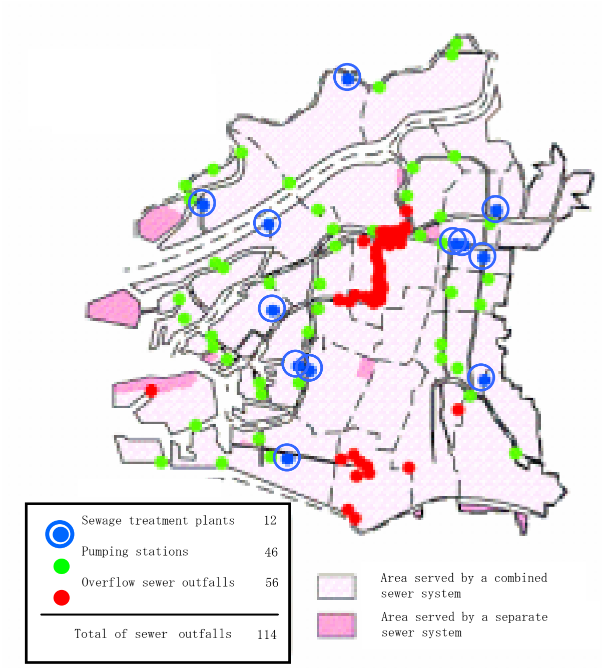


Fig. 1: Areas Served by Combined Sewer Systems

However, the combined sewer system causes contamination of public water bodies, because untreated sewage is discharged from CSO (combined sewer overflow) outfalls and pumping stations together with stormwater when combined flow exceeds the capacity of the sewer systems during wet weather.

The role of sewage systems in the conservation of water quality in public water bodies has become increasingly important. In order to create a pleasant and comfortable water environment, reduction of pollutant load on public water bodies during wet weather conditions is an urgent issue to be addressed. Accordingly, Osaka City is intensively carrying out projects for CSO (combined sewer overflow) control.

OUTLINE OF OSAKA CITY'S COMBINED SEWER SYSTEM IMPROVEMENT PROGRAM

In the combined sewer system improvement program, Osaka City has set its target as "reducing annual pollutant load from the combined sewer system in both dry and wet weather to the level of equal or less than that of a separate sewer system" and we are carrying out various improvement measures.

- Removal of solids accumulated in sewers
  - Installation of inverts on manhole bottoms
  - Replacement of sewers having inappropriate gradients
  - Reduction of inverted siphons
  - Flushing of sewers
- Storage of wet weather sewage
  - Stormwater reservoirs
  - Storage in the large trunk sewers(for flood control)
- Wastewater treatment during wet weather
  - Screening
  - Plate settling
  - Activated sludge process

As shown in Fig. 2, components of the program are categorized to the removal of pollutant sediments in sewers and storage and treatment of wet weather wastewater. We are implementing this program by combining these measures effectively in integrated manners.

Improvement of sewer structure

The Osaka city is located mostly on a soft alluvial ground. In addition, ground subsidence due to industrial use of an excessive amount of ground water for the rapid growth of industries during 1950s to 1970s has caused the inappropriate gradient of sewer, resulting in the accumulation of sediments in the sewer lines. Besides, sediment traps, which have been set at the bottom of manholes to facilitate sewer dredging, are the one of the major causes for accumulation of sediments during dry weather.

Therefore, in order to reduce pollutant load during wet weather, sediment traps were filled and instead invert channels were installed at the bottom of all manholes so that the sediments in sewers is transferred into sewage treatment plants as smooth as possible during period of dry weather. Sewers with inappropriate gradients are being rectified when they are renewed or replaced.

Storage of wet weather wastewater

The aim of temporal wastewater storing in wet weather is to capture the runoff water in the initial phase of a rainfall event, containing high concentration of pollutant for later conveyance to sewage treatment plants for treatment by activated sludge process after the storm. Osaka City is utilizing stormwater reservoirs and large trunk sewers constructed for flood control as well as for storage of stormwater.

1) Stormwater reservoirs

Stormwater reservoirs are designed to store the stormwater equivalent to 5 mm rain in the targeted areas. At present, they have been constructed at two locations in the city. Since the land for sewage facilities are limited, stormwater reservoirs are constructed with other facilities, for example, rapid sand filter units for advanced treatment and facilities other than sewage purposes in order to use limited space efficiently. An example of such facility is shown in Fig. 3.

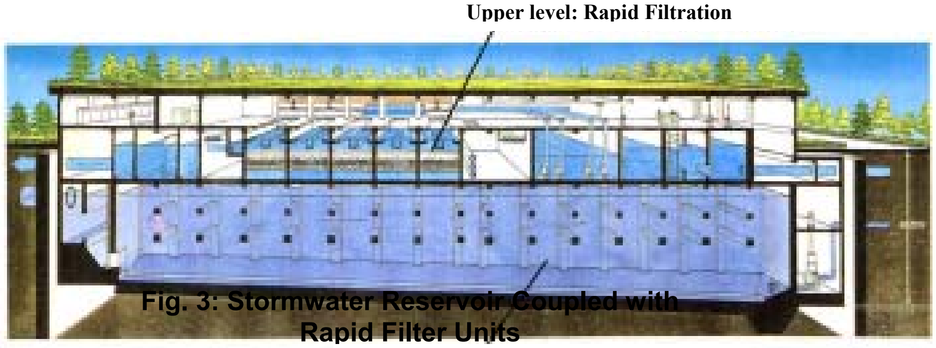


Fig. 3: Stormwater Reservoir Coupled with Rapid Filter Units

Combined Sewer
in Osaka City

As an another example, Dotonbori River, flowing through a downtown area of the city, is a valuable waterside amenity space and represents the unique sceneries of Osaka, however, there are 28 combined sewer overflow outfalls along Dotonbori River and its upstream Higashi-Yokobori River as shown in Fig. 4. Consequently, Osaka City has designated the both rivers as important water areas to carry out improvement program intensively for water quality protection, and decided to construct a large stormwater storage tunnel (6 m in diameter, 4 km in length, capacity of 140,000 m^3) designed to capture the whole volume of stormwater runoff for the designed rainfall event (a 10-year return period rainfall event). In parallel, pedestrian promenades are constructed along Dotonbori River to increase its amenity value.

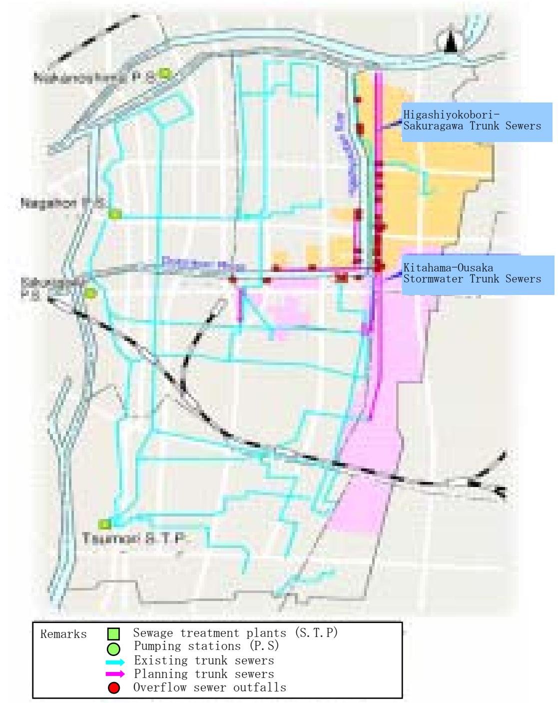


Fig. 4: Stormwater Storage Pipe along Dotonbori River for CSO Control

2) Utilization of large stormwater sewers

Currently, Osaka City is constructing large-scale stormwater tunnels and pumping stations for flood control, and some facilities have already been in use. Such large-scale stormwater sewers with large diameter are laid quite deep and are basically not used during dry weather and stormwater overflowing from existing sewers enters into them during wet weather. These large stormwater sewers are primarily used for discharging of stormwater runoff for controlling flood. In addition to this, in case of light rainfall, these can be used for storage of stormwater runoff instead of discharging for later conveyance to sewage treatment plants, which will results in the reduction of discharged pollutant load. An example of diversion structures is shown in Fig. 5.

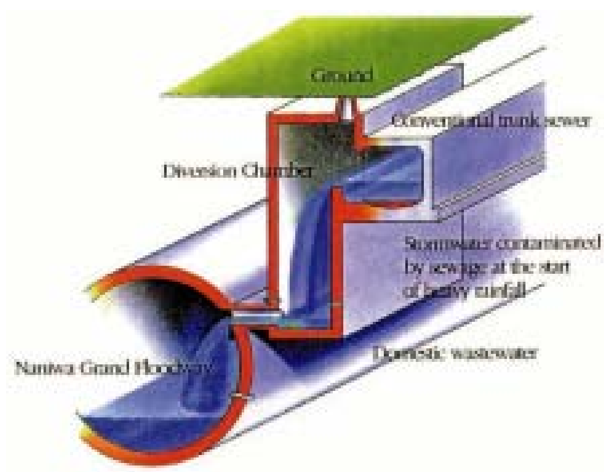


Fig. 5: Utilization of Large Stormwater Tunnel for CSO Control

Treatment of wet weather wastewater

In the current process in Osaka city, three times (3Qsh) of design peak hourly wastewater flow in dry weather (1Qsh) is supposed to be conveyed to sewage treatment plants during wet weather. Among 3Qsh, 1Qsh is treated by the activated sludge process, while the remaining 2Qsh is treated only by passing primary sedimentation tanks to remove solids and discharged into public water bodies (Fig. 6). However, discharged pollutant load of 2Qsh is still high due to the primary treatment of only sedimentation. Therefore, we have carried out studies and developed new method to treat the 2Qsh of wet weather wastewater by feeding it into the last cell of aeration tanks in the activated sludge process (Fig. 7), that is named as 3W Method (Wet Weather Wastewater treatment method)

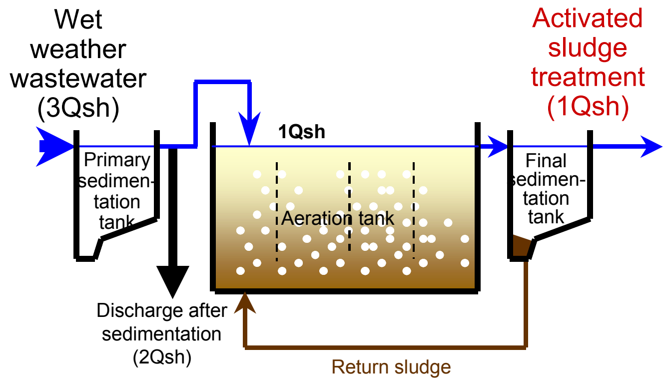


Fig. 6: Conventional Wastewater Treatment during Wet Weather

Since the treatment plants of Osaka City are equipped with channels for step feeding to be applicable for both conventional activated sludge process and step aeration process, 3W Method can be introduced with relatively small changes of existing facilities. Thus, this method is cost effective in construction and useful in ensuring immediate effect, we are planning to introduce the 3W Method to all 12 sewage treatment plants. As of March 2004, 3W Method is in use in Suminoe Treatment Plant and south treatment ficility of Hirano Treatment Plant.

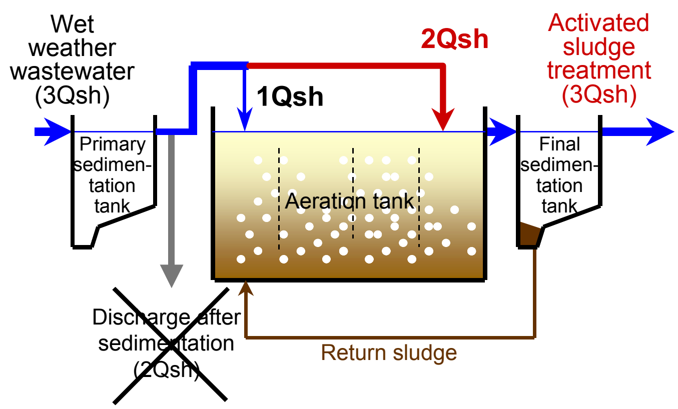


Fig. 7: Wet Weather Activated Sludge Treatment

WET WEATHER ACTIVATED SLUDGE PROCESS FOR COMBINED SEWER SYSTEM IMPROVEMENT

Principle of 3W Method

1) Quick pollutant removal by adsorption of activated sludge

In general, pollutants are adsorbed by the activated sludge in the first 30 minutes, and then decomposed gradually (Fig. 8). In 3W Method, the hydraulic retention time of wet weather wastewater in the final cell of aeration tank is as short as several tens of minutes. In spite of such a short time, pollutants are adsorbed to the activated sludge and then removed quickly.

Although the adsorption capacity of
activated sludge is limited, it is recovered as
activated sludge gradually decomposes
pollutants in the treatment process. In the
3W Method, activated sludge that has adsorbed pollutants in the final cell of an aeration tank, is conveyed to the final sedimentation tank and returned to the first cell as a return sludge. Then, as the
activated sludge goes through the first and
middle cells, pollutants are decomposed and
the activated sludge recovers its adsorption capacity before it reaches the final cell of the aeration tank. This continuous process ensures the stable treatment of 3W method. (Fig. 9)

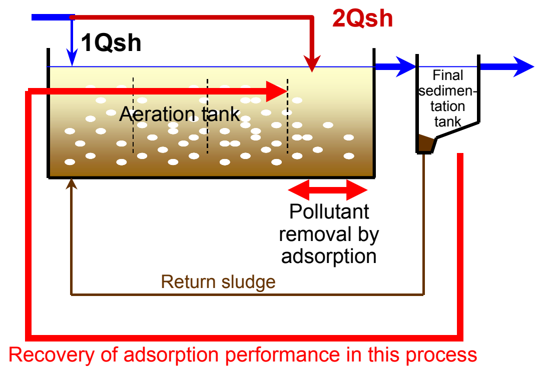


Fig. 9: Recovery of Activated Sludge's Adsorption Performance

2) Reduction of solids load on final sedimentation tanks by step feeding

In general, Camp's sedimentation theory is used for determining overflow rate. However this theory is not applicable for this case since because it gives the constant value of solids load on a final sedimentation tank regardless of the MLSS concentration. In the 3W Method, solid load is evaluated based on the flux theory.

At the just beginning of 3W Method operation, the MLSS in the final cell of the aeration tank is transferred to the final sedimentation tank. Since this concentration decreases immediately by the dilution, solids load on the final sedimentation tank does not become so high under the steady state operation.

Assuming that influent and effluent SS, stagnation of solids in the final sedimentation tank and activated sludge return sludge pipe, and withdrawal of excess sludge (production and decomposition of sludge) are negligible, then, in the

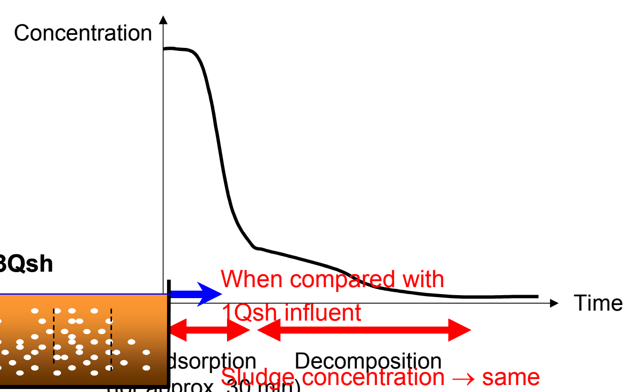
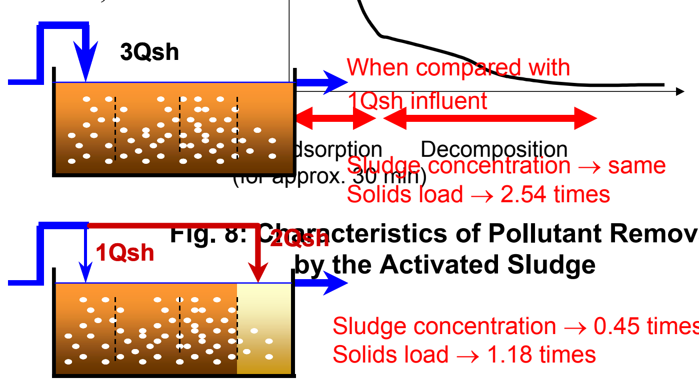


Fig. 8: Characteristics of Pollutant Removal by the Activated Sludge



(Assumption: influent/effluent SS negligible, with return rate of 30%)

Fig. 10: Comparison of Influent Solids Loads

case where wastewater of 3Qsh is fed into the first cell of the aeration tank without step-feeding with a return ratio of 30%, solids load reaches to 2.54 times that of 1Qsh treatment. On the other hand, when the step feeding is applied, sludge concentration in the final cell of the aeration tank is diluted to 0.45 times of 1Qsh treatment, resulting in reducing the solids load to approx. 1.18 times (Fig. 10).

The above fact shows that, in the 3W Method, the most important point is to cope with the initial stage of operation when the solids load is high. After this stage, there will be no serious problems posed as far as solids load is concerned.

Introduction of 3W Method into existing facility at Hirano Sewage Treatment Plant

The Hirano Sewage Treatment Plant consists of two treatment facilities; South and East treatment facilities. Both are operated under the anaerobic/aerobic activated sludge process and their maximum daily treatment capacities are as follows.

South treatment facility : 117,000 m^3/day
East treatment facility : 152,000 m^3/day
Total : 269,000 m^3/day

To verify the effectiveness of the 3W Method, this method was applied to the south treatment facility (maximum daily wastewater flow: 117,000 m^3/day) of the Hirano Sewage Treatment Plant and its performance was investigated. For this purpose, step gate No. 4 of the south aeration tank was automated to adjust its weir height automatically in response to the level of wet weather wastewater of the influent channel so that 1Qsh of wastewater flows into the aeration tank through step gate No. 1 and the remaining wastewater flows through step gate No. 4.

Wet weather conditions, rainfalls, and facility's operating conditions obtained by five operations in FY2001 are given in Table 1. The average water quality before and after application of the 3W Method is also shown in Table 2.

Table 1: Various Conditions During Wastewater Treatment by 3W Method (FY2000)

Date of Operation	Jun. 9, 2000	Sept. 11, 2000	Sept. 23, 2000	Oct. 20, 2000	Jan. 7, 2001
Total rainfall (mm)	30.9	165.0	27.9	17.1	16.9
Rainfall duration (hr)	10.5	36.2	4.8	6.8	8.8
Duration of treatment by 3W (hr)	3	45	5.6	9.7	11.8
Total treated amount (m^3)	30,324	469,639	62,008	97,418	102,896
Max. flow (m^3/hr)	11,599	13,534	13,151	12,656	11,936
(Qsh)	1.98	2.31	2.25	2.36	2.45
Max. OFR in final sedimentation tank (m/day)	49	56	54	57	59
Initial water temperature (°C)	21	29	28	25	17
Initial MLSS (mg/L)	1,930	1,510	500[a)]	790	1,850

Initial SVI (mL/g)	135	86	101[a)]	127	97

* a) measured just after the start of 3W operation.
* 11/12 tanks are used on Oct. 20, 2000; 10/12 tanks are used on Jan. 7, 2001

Table 2: Water Quality of 3W Method (FY2000)

Sample	Parameter	Jun. 9, 2000	Sept. 11, 2000	Sept. 23, 2000	Oct. 20, 2000	Jan. 7, 2001
Influent of primary sedimentation tank	SS (mg/l)	148 (100 - 250)	104 (54 - 190)	153 (48 - 270)	140 (27 - 340)	326 (250 - 420)
	BOD (mg/l)	58 (44 - 67)	68 (31 - 95)	64 (29 - 98)	89 (32 - 250)	343 (240 - 450)
Effluent from primary sedimentation tank	SS (mg/l)	---	40 (34 - 51)	58 (37 - 94)	50 (36 - 69)	98 (65 - 130)
	BOD (mg/l)	---	40 (22 - 58)	40 (29 - 51)	50 (26 - 72)	125 (100 - 160)
Treated water	SS (mg/l)	5.7 (4.0 - 6.7)	6.3 (5.0 - 7.0)	8.4 (7.0 - 11.0)	10.0 (8.0 - 14.0)	15.1 (7.6 - 27.0)
	BOD (mg/l)	2.0 (2.0 - 2.0)	3.8 (3.0 - 5.0)	4.6 (3.0 - 6.0)	7.4 (6.0 - 10.0)	13.7 (6.0 - 21)

* BOD of treated water is nitrification-inhibited BOD. "---" denotes faulty measurement.

Performance of the 3W Method

The results showed that the 3W Method could reduce effluent pollutant load by 59 to 91% in SS (73% in average) and 27 to 78% in BOD (61% in average) from that of conventional processes employing only a primary treatment (Fig.11).

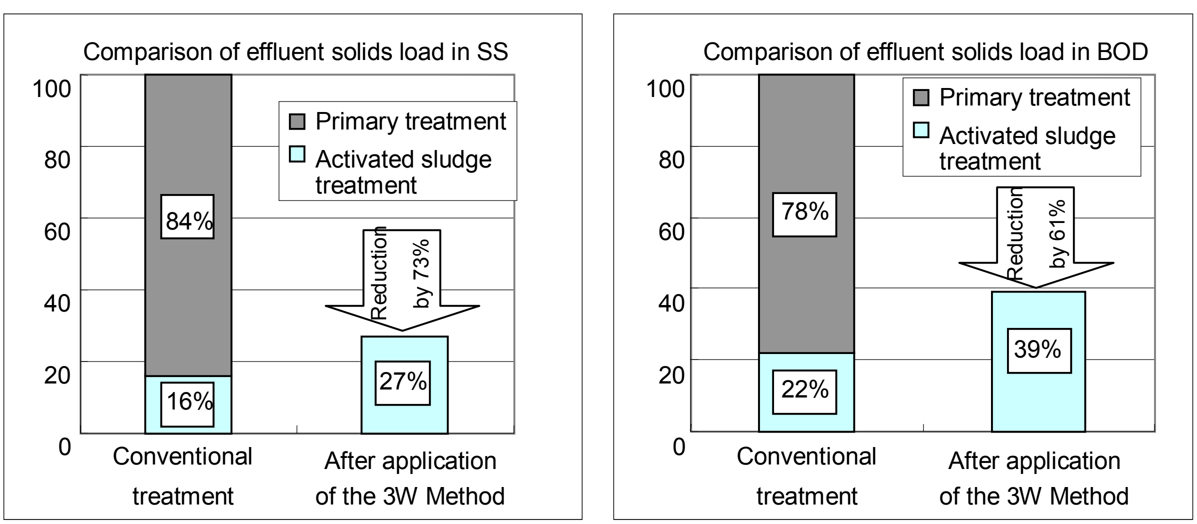


Fig. 11: Effect of the 3W Method in Effluent Solids Load Reduction during Wet Weather

FUTURE PROSPECTS FOR THE 3W METHOD APPLICATION

These investigation results showed that the 3W Method is one of the effective approaches for improvement of combined sewer systems. By the end of March 2004, 3W Method is introduced at Suminoe Sewage Treatment Plant and south treatment facility of Hirano Sewage Treatment Plant as mentioned above. Furthermore, various data are still being collected and further studies are being conducted through the practical operation of these facilities in order to consider the following subjects.

Simultaneous use with advanced wastewater treatment of N and P

Regarding the simultaneous use with advanced wastewater treatment of N (nitrogen) and P (phosphorus), an experiment was carried out to confirm if the 3W Method could work with advanced wastewater treatment (two-step feeding type nitrification/denitrification process) without giving adversely effects on this.

The results showed that, though the treatment of nitrogen and phosphor tends to be somewhat disrupted shortly, nitrogen removal performance was recovered in five hours after completion of the 3W Method operation and phosphorous removal performance in about three days. Disruption of nitrogen treatment was caused by ammonia nitrogen included in the effluent from the aeration tank due to the short retention time of wastewater fed into the final cell. The phosphorus treatment disruption is caused by DO brought by the influent of wet weather wastewater.

The above-discussed phenomena are not subject to the 3W Method operation but generally to the combined sewer systems with biological nitrogen and phosphorus treatment method. Therefore, these will not pose any significant problems to simultaneous use of the 3W Method and advanced treatment of N and P.

Simultaneous use with carrier-added activated sludge process

Due to the limited space for new sewage treatment plants in Osaka City, carrier-added two-step feeding type nitrification/denitrification process (carrier-added AOAO process) is currently considered the best option for advanced wastewater treatment for nitrogen removal that can be introduced into existing sewage treatment plants. The facility for carrier-added AOAO process was installed in FY2003 at Konohana Sewage Treatment Plant in Osaka city. Soon after the facility is in operation, investigation will be conducted to clarify the effectiveness of simultaneous use with a carrier-added AOAO process and 3W method.

Furthermore, when the 3W method is used in combination with carrier-added process, carrier separation screen that can allow 3Qsh flow through has to be developed and the prevention of clogging of the screen need to be carefully examined.

CONCLUSION

Subjects arising from the combined sewer systems are common to the cities having this type of facilities. As Japanese citizens have gotten more interest on surrounding water environment and realizing the higher level of water quality of public water bodies is getting to be expected, disadvantages of combined sewer systems have been highlighted and their improvement has attracted public attention.

Under such circumstances, Osaka City is investigating current situations of wet weather wastewater discharged from the stormwater outfalls. The investigation will be continued in the future in order to accumulate more information experiences. By effectively using these investigation results, we are going to develop several possible measures for improving the existing combined sewer systems. In addition to this, it may be our duty to obtain the understanding of the relevant stakeholders before implementing the combined sewer system improvement by disclosing the expected effects of the improvement and the costs for each measure to the citizens in due course.

In order to meet the demand for efficient and economical improvement for combined sewer systems under the current financial constraints of Osaka City, soft approaches which ensure appropriate operation and management of these facilities, for instance, capturing the first flush of wet weather wastewater without losing its timing are important as well as the construction of hard-facilities such as stormwater reservoirs. Also, further modification and refinement of existing facilities, including the continuous treatment of wet weather wastewater mentioned above have to be considered. By effectively implementing these measures, improvement of combined sewer systems will be achieved as soon as possible.

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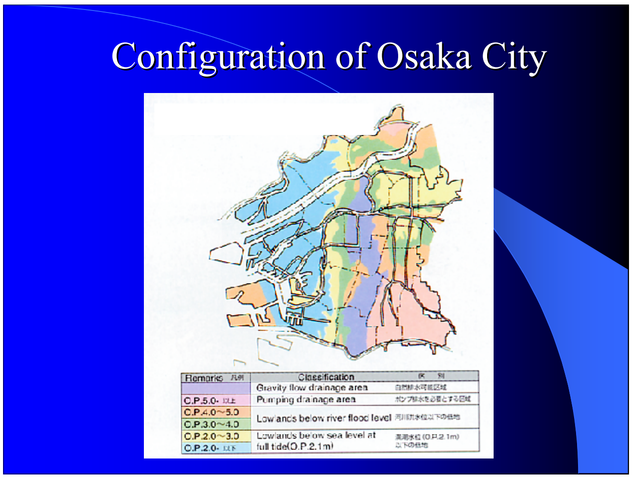
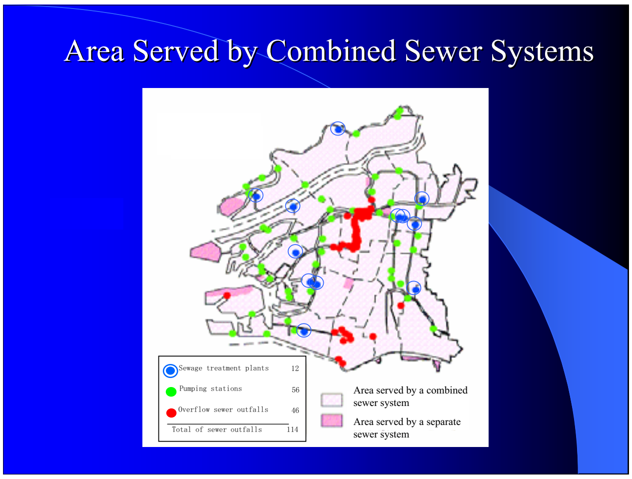
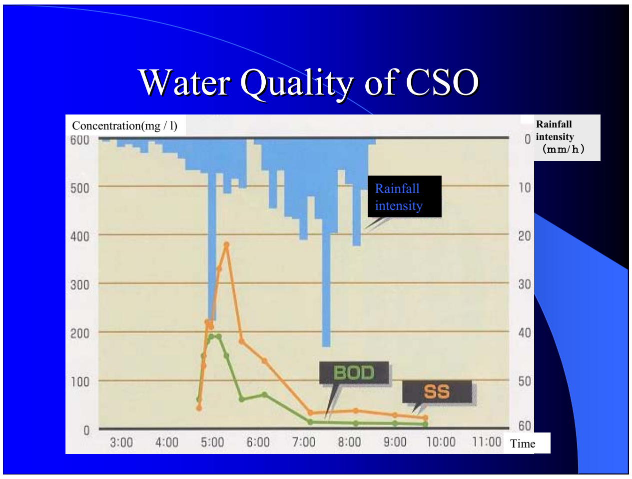
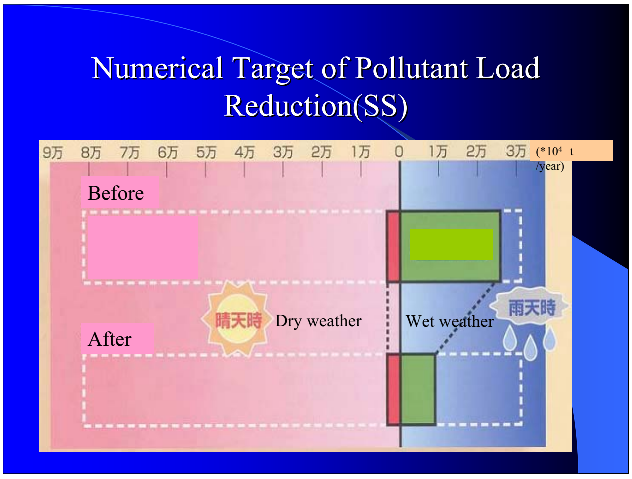
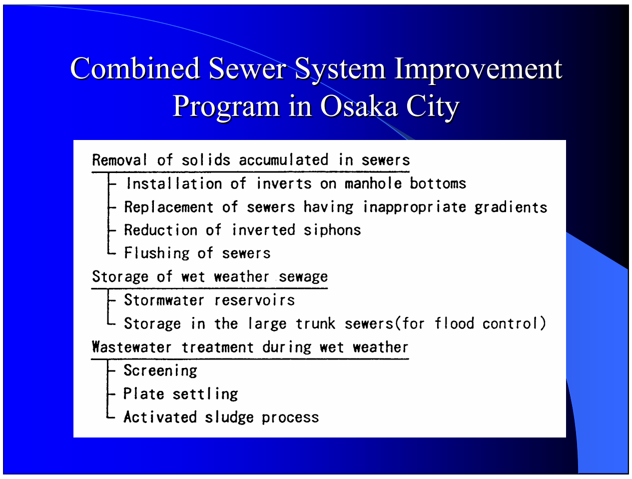
Location of Osaka City
Lake Biwa
Kyoto
Yodo River
Kobe
OSAKA CITY
Awaji Island
Nara
Kansai International Airport
Osaka
Tokyo

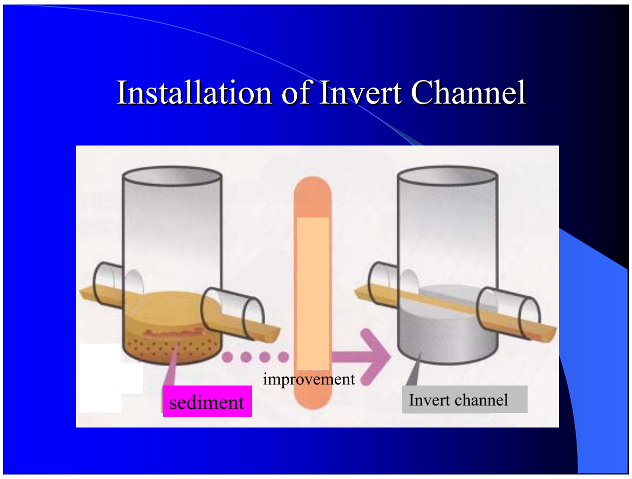

Configuration of Osaka City
Classification
Gravity flow drainage area
Pumping drainage area
Lowlands below river flood level
Lowlands below sea level at full tide(O.P. 2.1m)

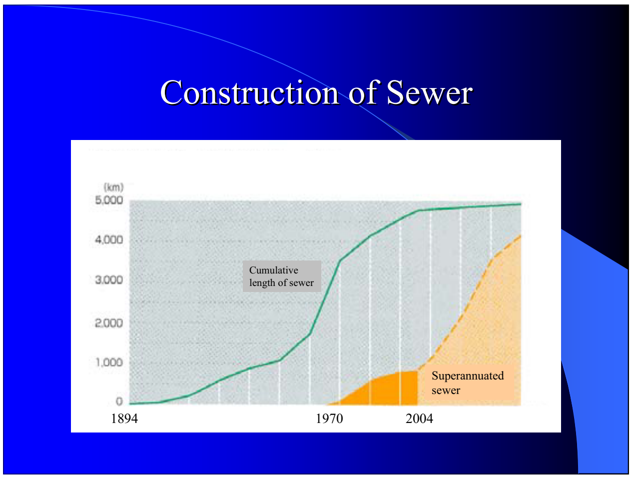

Area Served by Combined Sewer Systems
Sewage treatment plants 12
Pumping stations 56
Overflow sewer outfalls 46
Total of sewer outfalls 114
Area served by a combined sewer system
Area served by a separate sewer system

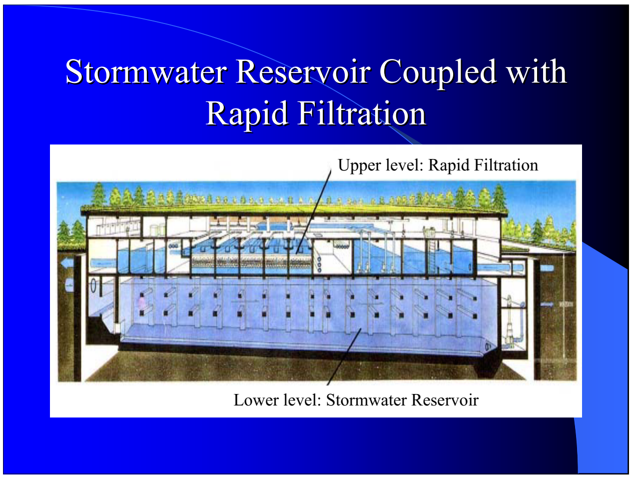

Water Quality of CSO
Concentration(mg / l)
Rainfall intensity (mm/h)
Rainfall intensity
BOD
SS
3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 Time


Numerical Target of Pollutant Load Reduction(SS)
9万 8万 7万 6万 5万 4万 3万 2万 1万 0 1万 2万 3万
Before
After
晴天時 Dry weather
Wet weather 雨天時

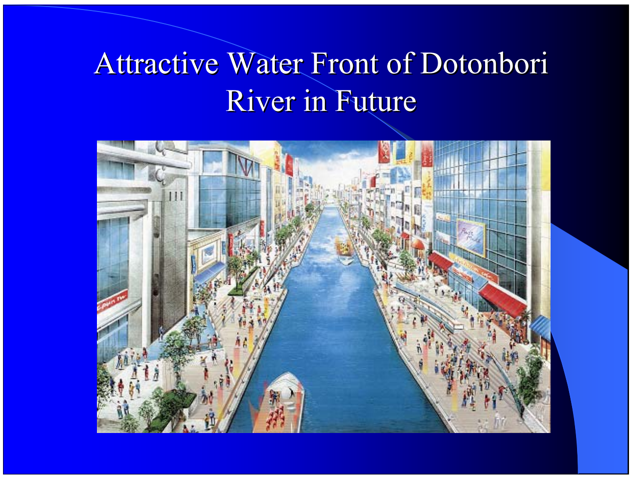

Combined Sewer System Improvement Program in Osaka City
Removal of solids accumulated in sewers
Installation of inverts on manhole bottoms
Replacement of sewers having inappropriate gradients
Reduction of inverted siphons
Flushing of sewers
Storage of wet weather sewage
Stormwater reservoirs
Storage in the large trunk sewers(for flood control)
Wastewater treatment during wet weather
Screening
Plate settling
Activated sludge process

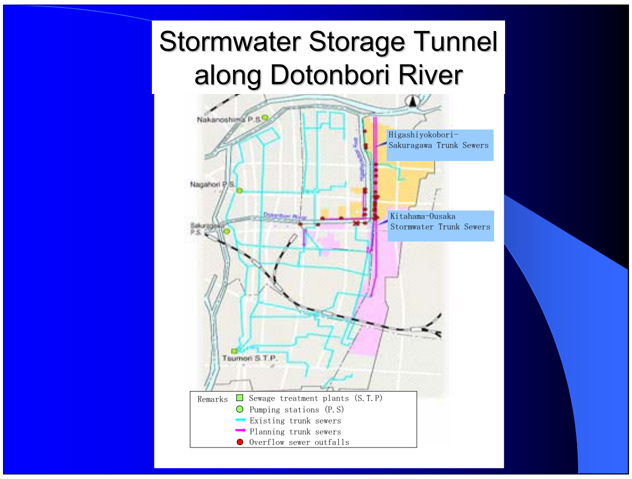

Installation of Invert Channel
improvement
sediment
Invert channel

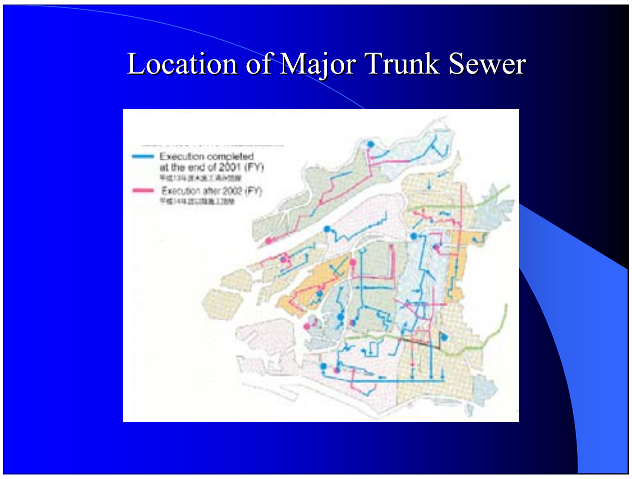

Construction of Sewer
(km)
5,000
4,000
3,000
2,000
1,000
0
Cumulative length of sewer
Superannuated sewer
1894
1970
2004

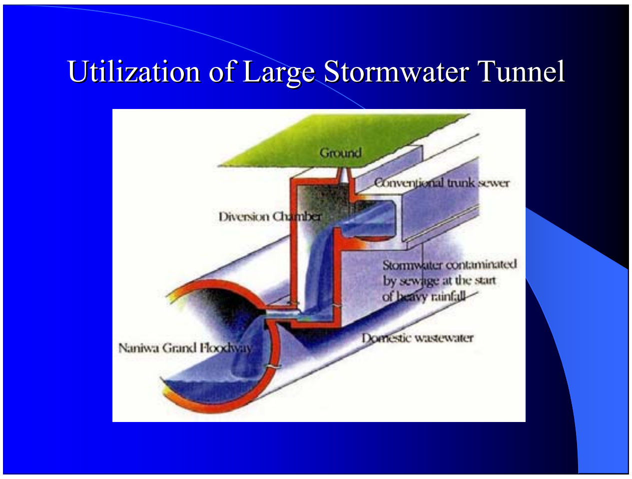

Stormwater Reservoir Coupled with Rapid Filtration
Upper level: Rapid Filtration
Lower level: Stormwater Reservoir

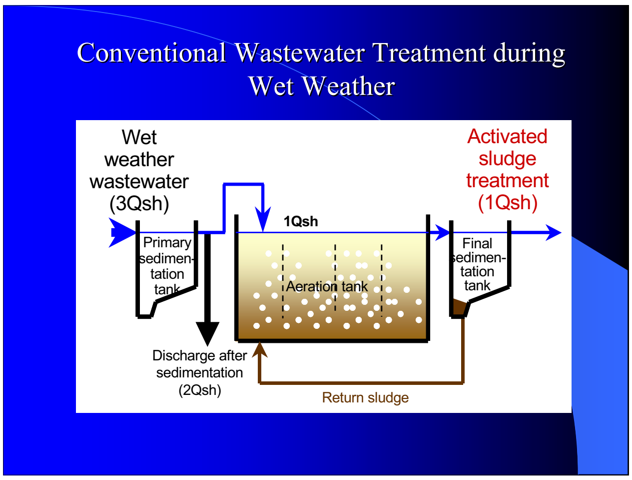

Present Condition of Dotonbori River

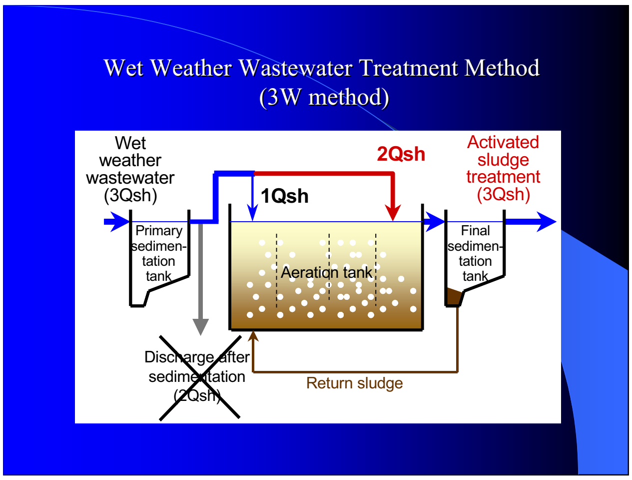

Attractive Water Front of Dotonbori River in Future


Stormwater Storage Tunnel along Dotonbori River
Nakanoshima P.S.
Nagahori P.S.
Tsumori S.T.P.
Higashiyokobori-Sakuragawa Trunk Sewers
Kitahama-Ousaka Stormwater Trunk Sewers
Remarks
Sewage treatment plants (S.T.P)
Pumping stations (P.S)
Existing trunk sewers
Planning trunk sewers
Overflow sewer outfalls


Location of Major Trunk Sewer
Execution completed at the end of 2001 (FY)
Execution after 2002 (FY)

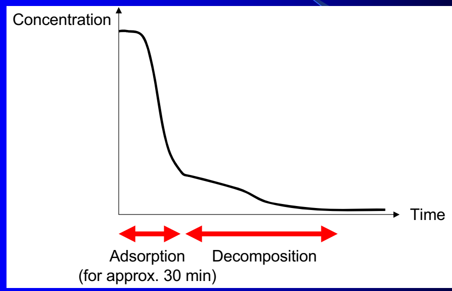

Utilization of Large Stormwater Tunnel
Ground
Conventional trunk sewer
Diversion Chamber
Stormwater contaminated by sewage at the start of heavy rainfall
Naniwa Grand Floodway
Domestic wastewater


Conventional Wastewater Treatment during Wet Weather
Wet weather wastewater (3Qsh)
Activated sludge treatment (1Qsh)
1Qsh
Primary sedimen-tation tank
Aeration tank
Final sedimen-tation tank
Discharge after sedimentation (2Qsh)
Return sludge

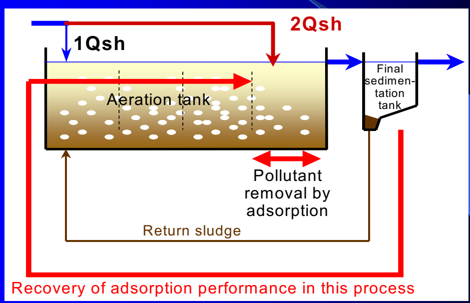

Wet Weather Wastewater Treatment Method (3W method)
Wet weather wastewater (3Qsh)
2Qsh
Activated sludge treatment (3Qsh)
1Qsh
Primary sedimen-tation tank
Aeration tank
Final sedimen-tation tank
Discharge after sedimentation (2Qsh)
Return sludge

Step Gate

Characteristics of Pollutant Removal by the Activated Sludge



Recovery of Activated Sludge's Adsorption Performance



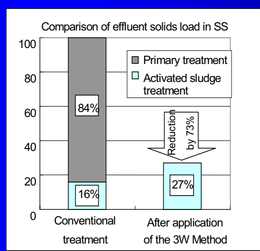
Conditions during Wastewater Treatment by 3W Method

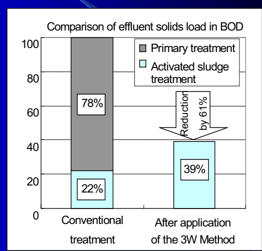
Date of Operation	Jun. 9, 2000	Sept. 11, 2000	Sept. 23, 2000	Oct. 20, 2000	Jan. 7, 2001
Total rainfall (mm)	30.9	165.0	27.9	17.1	16.9
Rainfall duration (hr)	10.5	36.2	4.8	6.8	8.8
Duration of treatment by 3W (hr)	3	45	5.6	9.7	11.8
Total treated amount (m^3)	30,324	469,639	62,008	97,418	102,896
Max. flow (m^3/hr)	11,599	13,534	13,151	12,656	11,936
(Qsh)	1.98	2.31	2.25	2.36	2.45
Max. OFR in final sedimentation tank (m/day)	49	56	54	57	59
Initial water temperature (°C)	21	29	28	25	17
Initial MLSS (mg/L)	1,930	1,510	500[a)]	790	1,850
Initial SVI (mL/g)	135	86	101[a)]	127	97

Water Quality of 3W Method

Sample	Parameter	Jun. 9, 2000	Sept. 11, 2000	Sept. 23, 2000	Oct. 20, 2000	Jan. 7, 2001
Influent of primary sedimentation tank	SS (mg/l)	148 (100 - 250)	104 (54 - 190)	153 (48 - 270)	140 (27 - 340)	326 (250 - 420)
	BOD (mg/l)	58 (44 - 67)	68 (31 - 95)	64 (29 - 98)	89 (32 - 250)	343 (240 - 450)
Effluent from primary sedimentation tank	SS (mg/l)	---	40 (34 - 51)	58 (37 - 94)	50 (36 - 69)	98 (65 - 130)
	BOD (mg/l)	---	40 (22 - 58)	40 (29 - 51)	50 (26 - 72)	125 (100 - 160)
Treated water	SS (mg/l)	5.7 (4.0 - 6.7)	6.3 (5.0 - 7.0)	8.4 (7.0 - 11.0)	10.0 (8.0 - 14.0)	15.1 (7.6 - 27.0)
	BOD (mg/l)	2.0 (2.0 - 2.0)	3.8 (3.0 - 5.0)	4.6 (3.0 - 6.0)	7.4 (6.0 - 10.0)	13.7 (6.0 - 21)

Effect of 3W Method in Effluent Solids Load Reduction during Wet Weather





Key Factors to be Considered

- Continuous research and studies
- Cost benefit
- Proper combination of projects
- Soft approach
- Stakeholder's involvement