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A New Approach to CSO Control

: A Unique Device for Preventing Sludge Accumulation in Inverted Siphons

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Location of Osaka, Japan

Outlines of Osaka Sewage System

- Sewer constructed since 16th century.
  - Wastewater was discharged to sewer ditches.
- Sewer Treatment since 1940.
  - Activated sludge system.
- 12 Sewage Treatment Plants
  - Capacity : 750,000 gal/day (=2,844,000 m^3/day)
- Total Sewer Length : 3,000mile (=4,800km)
  - Combined sewer system

Problem of Inverted Siphons

- Sludge or solids are
  - Easily accumulated in inverted siphons in dry weather
  - Flashed out and discharged from the CSO outfall into the rivers in wet weather

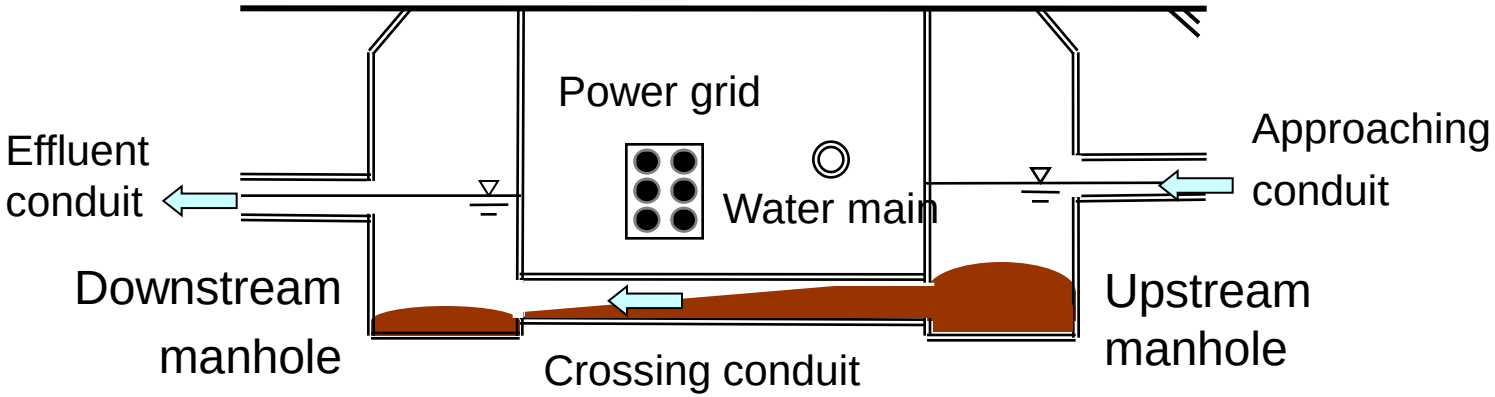


Fig. Cross section view of the typical inverted siphon

Pollution Source of CSOs

- 45 CSO outfalls and more than 100 inverted siphons in Osaka city central.

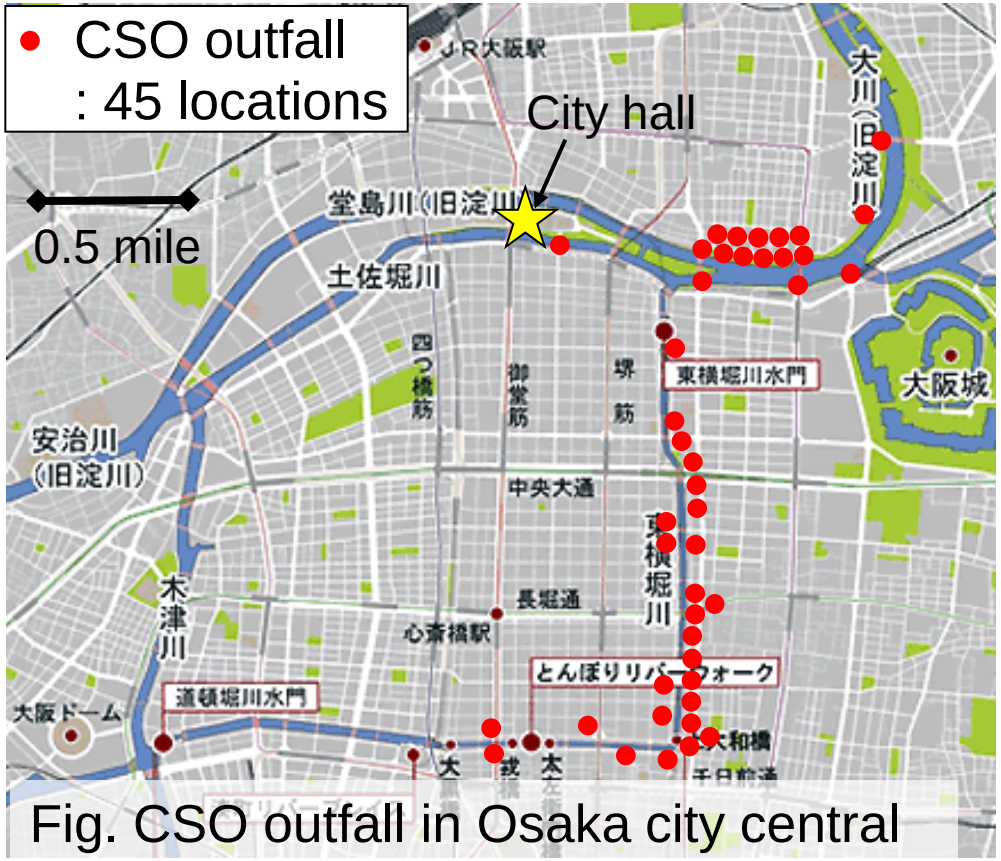


Fig. CSO outfall in Osaka city central

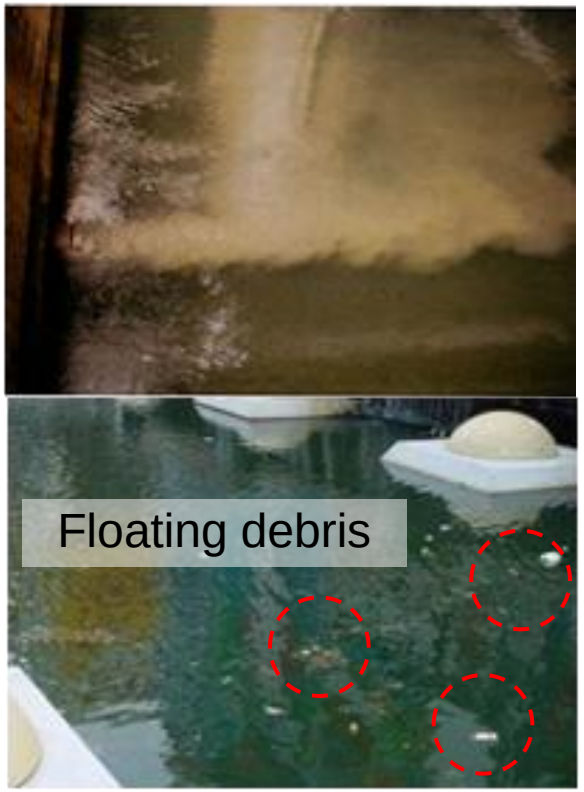


Photo: CSO outfall in wet weather

Mechanism of New Approach

- Objective
  - Preventing sludge accumulation
  - Non power device, easy setting & maintenance
- Hint
  - Sludge draining system in final settling tank
  - Sludge is forced up by the hydraulic head

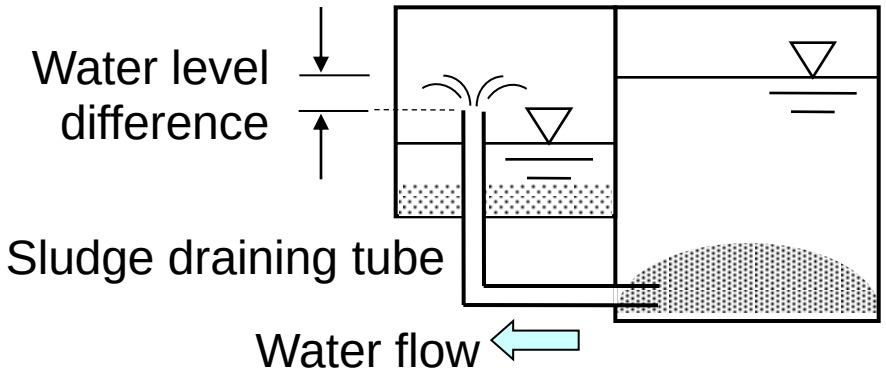


Fig. Telescopic-type sludge draining pipe

Improvement of Inverted Siphons

- Device consists of
  - Weir to create hydraulic head
  - Tube to draw up the sludge and solids
- We expect to reduce the accumulation of sludge in dry weather.

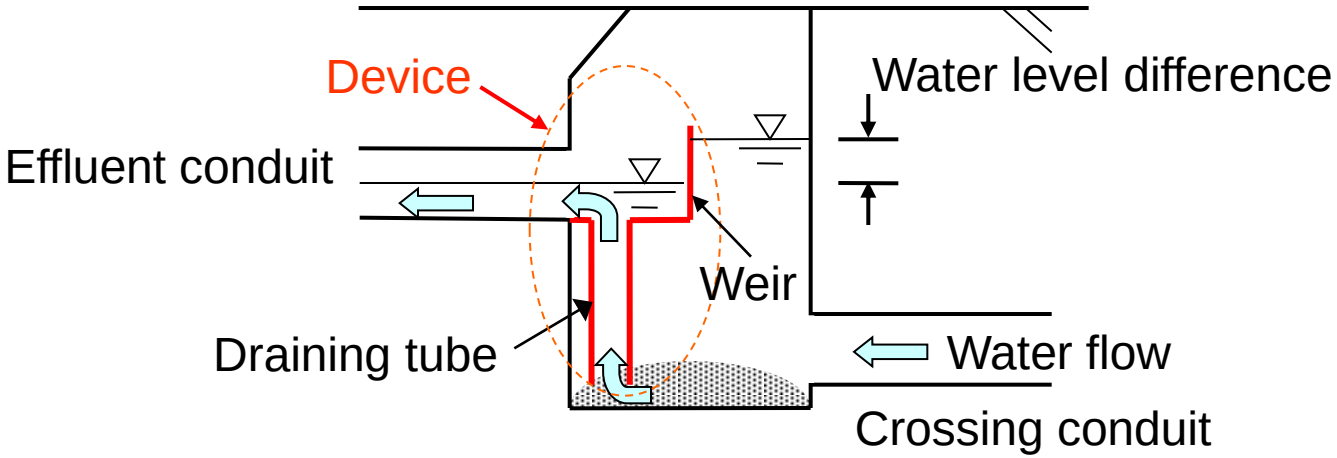


Fig. Mechanism of the device for preventing sludge accumulation

Stratification in inverted siphon

- Stratification of accumulated solids
  - Scum: Floats such as oil ball
  - Supernatant: MLSS < 1000 ppm
  - Sludge: MLSS ≧ 1000 ppm
  - Deposited soil and silt: Gravel

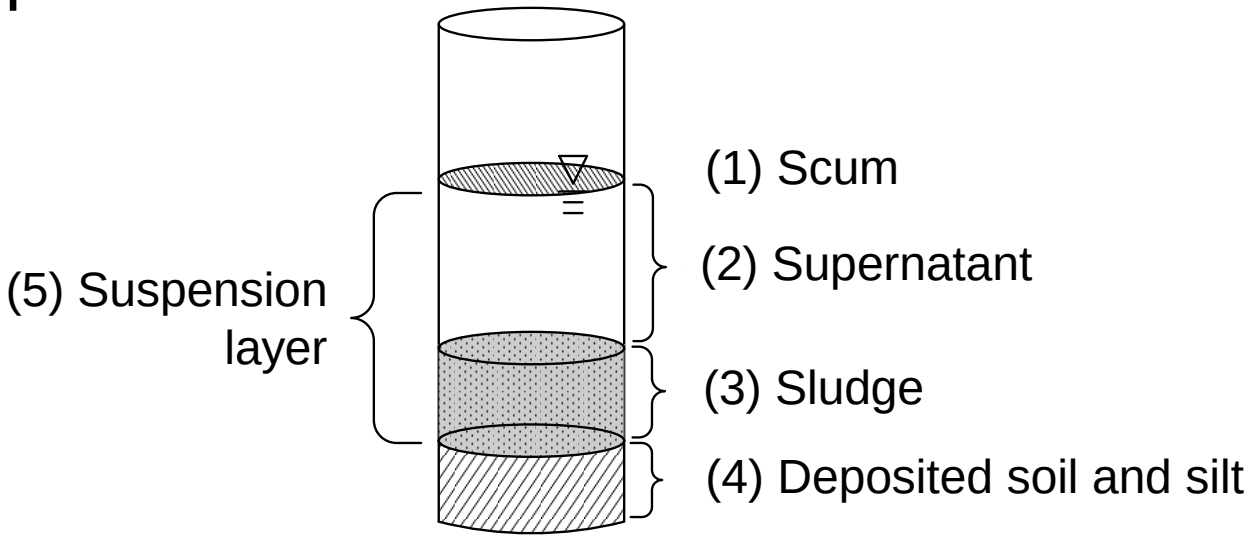


Fig. Cross section view of manhole in inverted siphon (dry weather)

Field Survey of Inverted Siphons

Table: Relationship of flow velocity and accumulated sludge in inverted siphon

No.	Velocity (cm/s)	Sludge: Downstream manhole	Sludge: Upstream manhole
A	29.5	+	0
B	25.5	+	+
C	8.0	++	+
D	6.5	+	+
E	6.0	0	0
F	5.5	++	+++
G	5.2	++	+
H	5.0	++	+++
I	4.0	+	0
J	3.5	++	0
K	3.5	++	0
L	3.3	+++	0
M	3.3	+++	0
N	2.1	++	+++

- Velocity is over 6 cm/s, sludge tends not to accumulate easily.

Velocity: flow velocity of the crossing conduit in inverted siphon

+~+++: thickness of accumulated sludge

+: 0 < sludge layer < 25 cm

++: 25 cm < sludge layer

+++: over the effluent conduit

Hydraulic Model Experiment

Hydraulic Model Experiment

- Objective
  - to check the effect of this device for preventing sludge accumulation
  - to establish the design specifications
- Procedure
  - First, to check the reproducibility of the accumulation of sludge using PVF cubes
  - Next, to install the device in the model, and seek the best specifications by adjusting the parts of device

Experimental Conditions

Table: PVF cubes as model solids

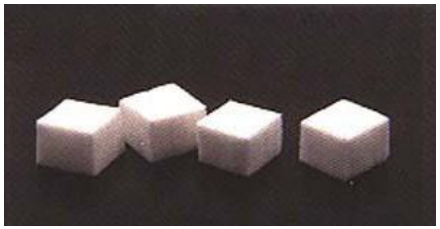
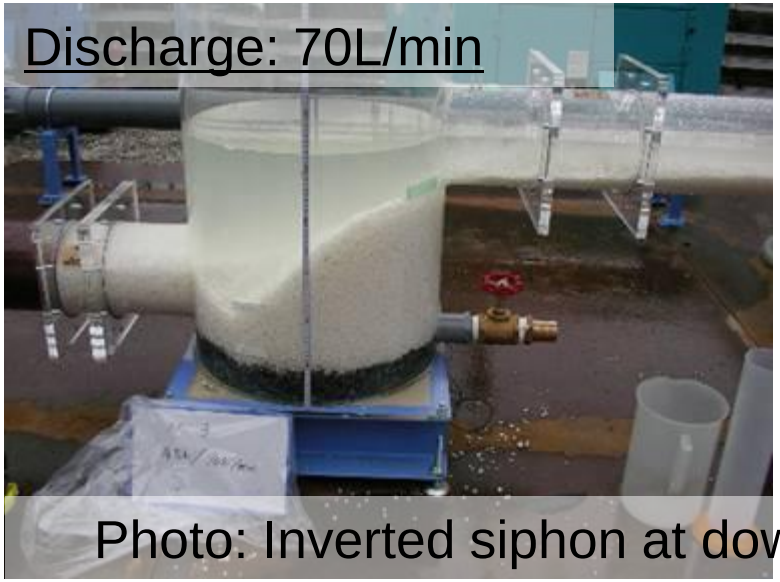
Specifications	Appearance
■Material：Poly Vinyl Formal ■Shape：Cube (4mm × 4mm× 4mm) ■Specific gravity：1.01～1.03 (in wet) ■Porosity：87～93%	

Table: Defined flow in dry and wet weather conditions

Type	Discharge (L/min)	Flow velocity of crossing conduit (cm/sec)	Remarks
Dry weather condition	6	0.3	Minimum flow
	40	2.1	Average flow
	70	3.7	Maximum flow
Wet weather condition	100	5.3	Minimum flow
	1,400	74	Designed flow

Result of Reproducibility

- Solids (PVF cubes) were
  - not flushed out with the maximum flow under dry weather conditions (70L/min); left photo.
  - but flushed out at the designed flow for wet weather conditions (1,400L/min); right photo.



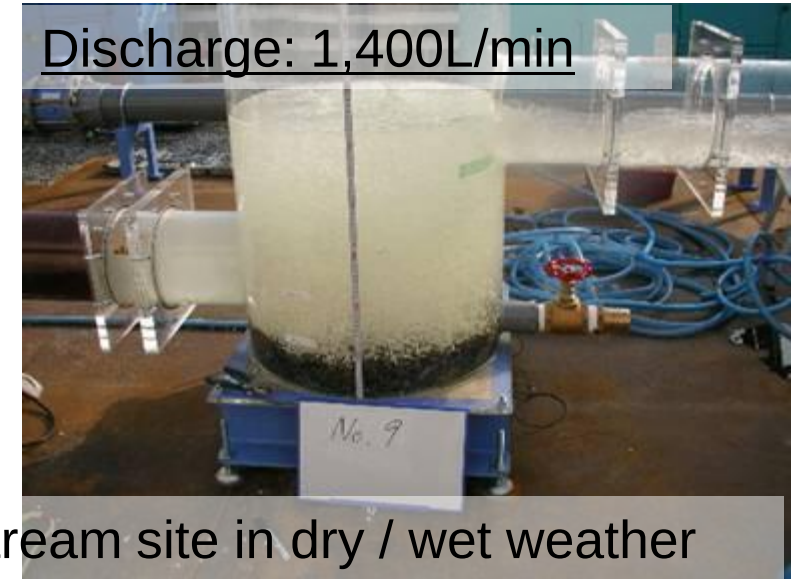
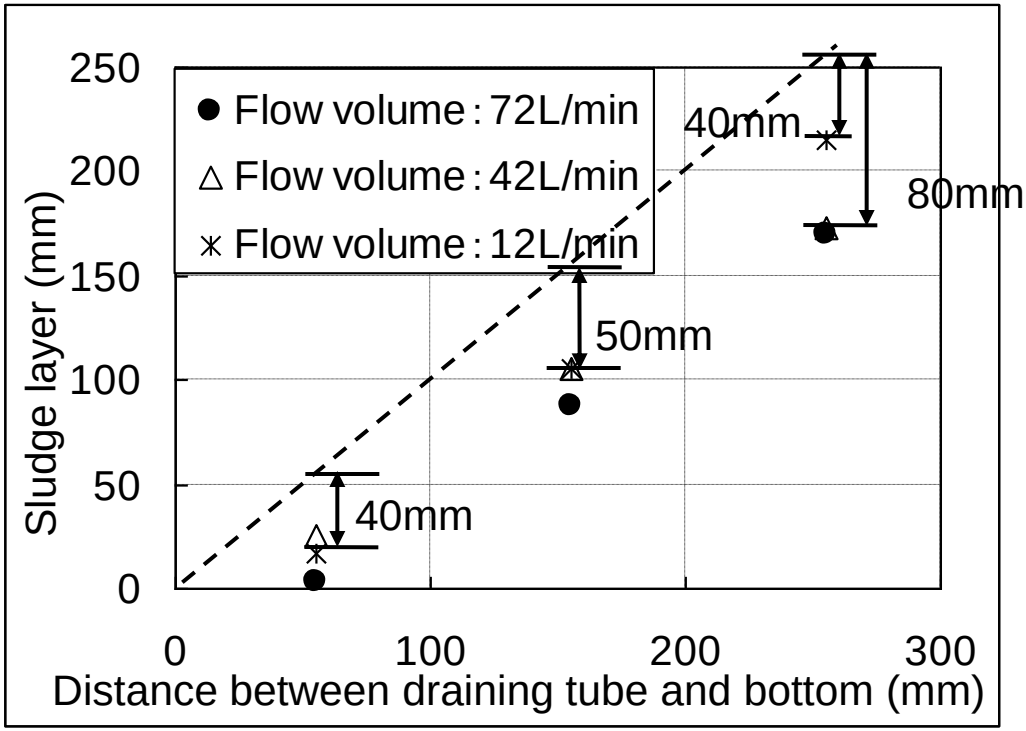
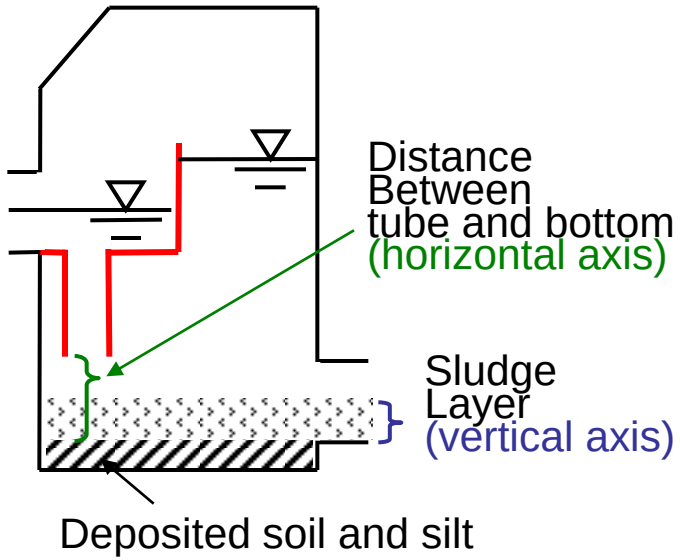


Photo: Inverted siphon at downstream site in dry / wet weather

Range of Removing Sludge Layer

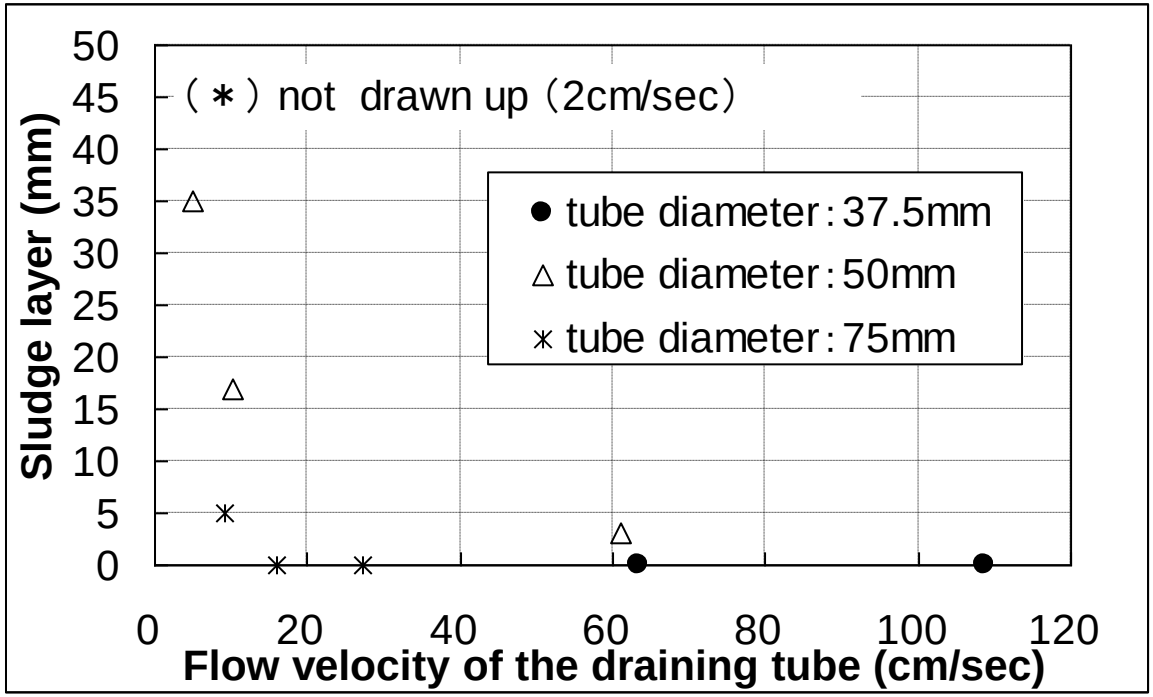
- Under 40 ~ 50 mm (80 mm maximum) from the bottom of the tube.





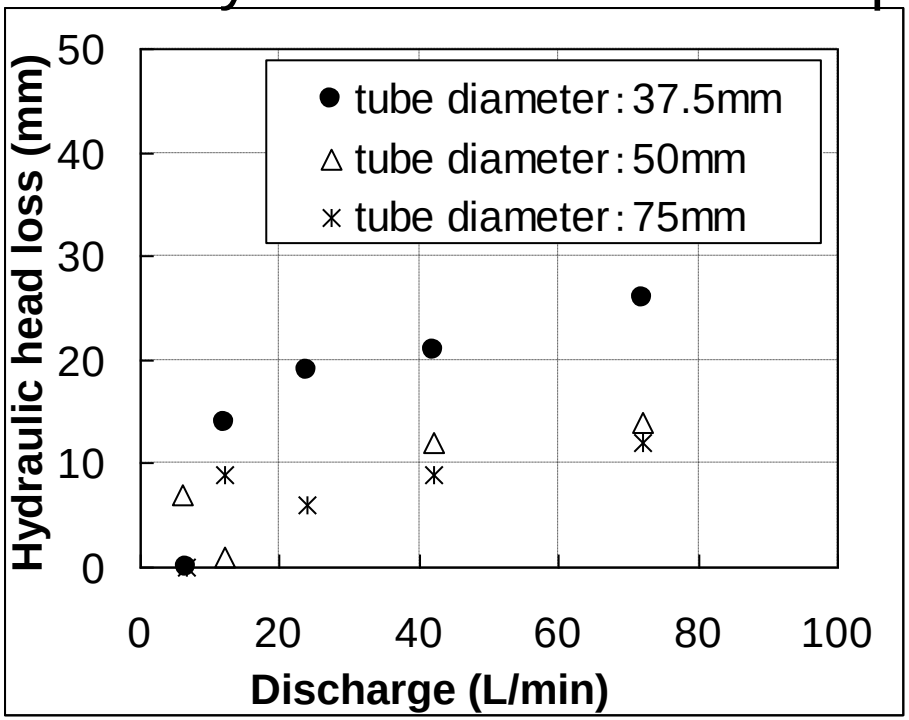
Flow Velocity and Drawing Effect

- More than 5 to 10 cm/sec, most of sludge is drawn up .
- The smaller pipe diameter is, the thinner sludge layer is.

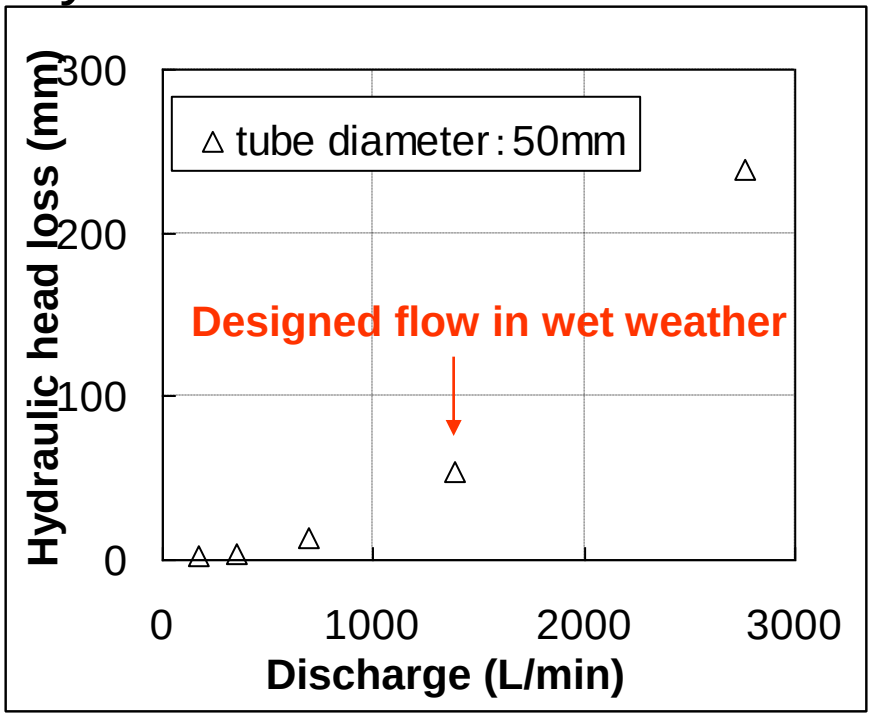


Hydraulic Head of Device

- Only 25 mm (full scale: 50mm) in dry weather .
- About 50mm (full scale: 100mm) in wet weather.
  - If the flow is more than designed stormwater flow, hydraulic head loss is rapidly increased.



Hydraulic head loss of Device in Dry Weather

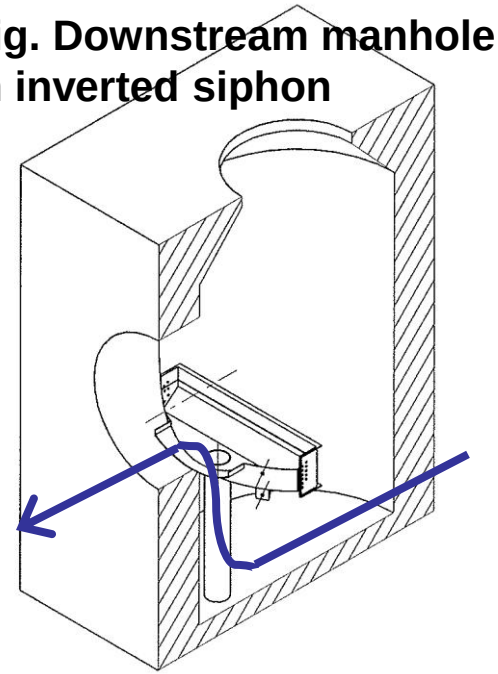


That of Inverted Siphon in Wet Weather

Characteristics of Device

- Materials & Cost
  - Weir: SUS304, Tube: PVC
  - Less than 6,000 dollars
- Design conditions
  - Flow Velocity in tube > 10cm/sec
  - Tube Diameter: 10cm (or more)
  - Tube Length: until 50mm above the bottom
- Application
  - Small inverted siphon: connected pipe is less than about 800 mm in diameter.

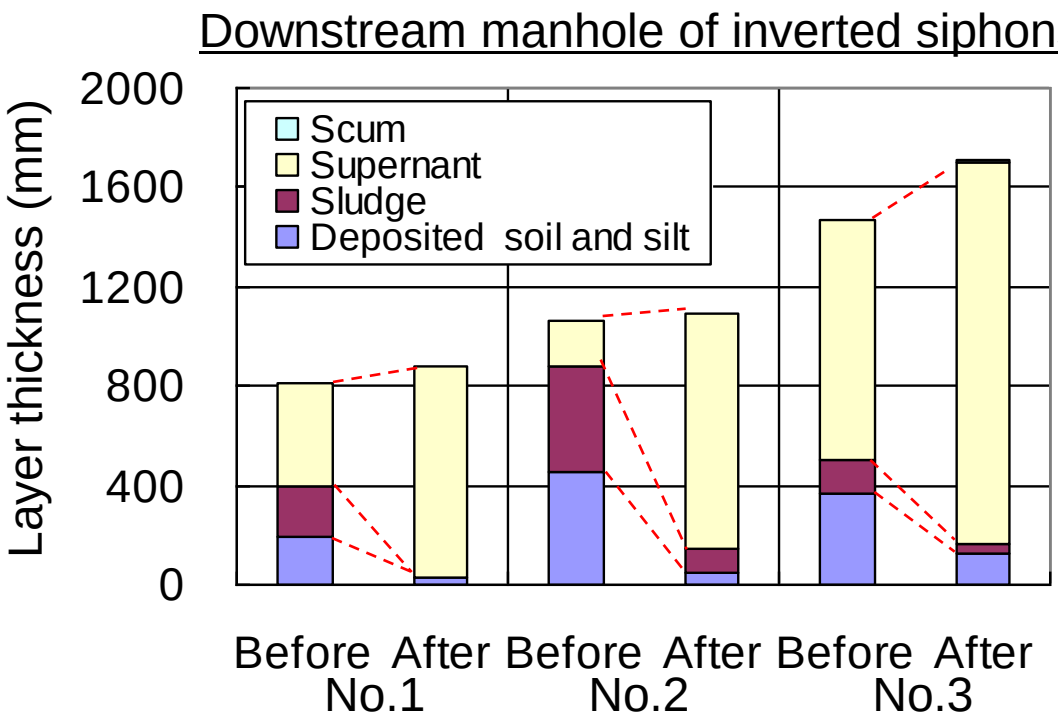
Fig. Downstream manhole in inverted siphon



Monitoring

- Device was installed at three different sites.

Results ~ Downstream manhole of inverted siphons ~



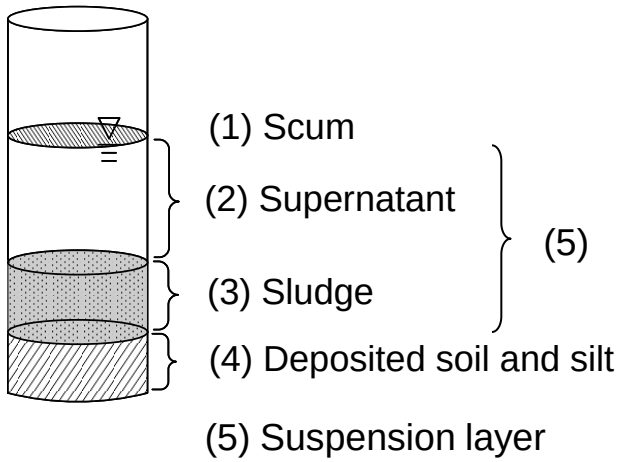


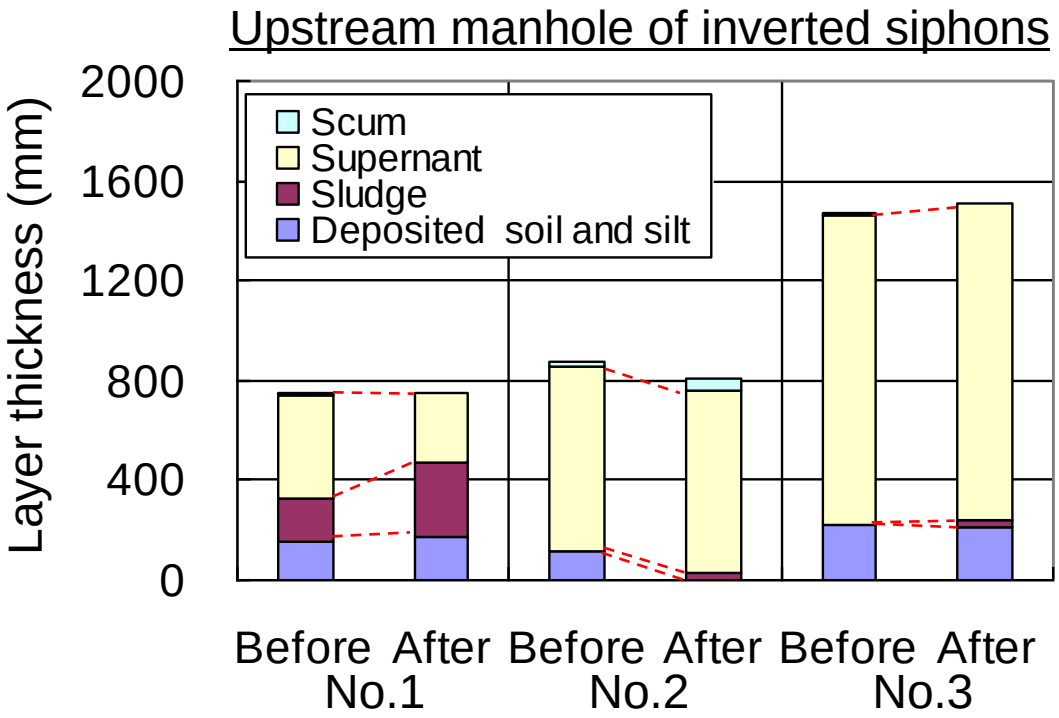
Fig. Stratification in manhole

Fig. Layer thickness of accumulation before and after installing the device

Table: Water quality of suspension layer in downstream manhole

	No.1			No.2			No.3		
	Before		After	Before		After	Before		After
BOD(mg/L)	615	→	260	8000	→	195	285	→	240
SS(mg/L)	710	→	280	6700	→	165	126	→	235

Results ~ Upstream manhole of inverted siphons ~



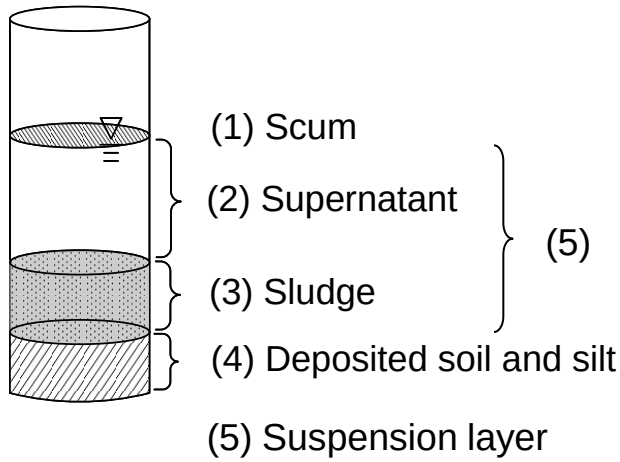


Fig. Stratification in manhole

Fig. Layer thickness of accumulation before and after installing the device

Table: Water quality of suspension layer in upstream manhole

	No.1			No.2			No.3		
	Before		After	Before		After	Before		After
BOD(mg/L)	5500	→	1700	340	→	175	210	→	190
SS(mg/L)	6050	→	2000	175	→	195	113	→	150

Results ~Improvement of pollution load~

- BOD-accumulation* is reduced to 1/3, the best result is 1/10.

*BOD-accumulation is calculated by multiplying BOD by the inner volume of the inverted siphon.

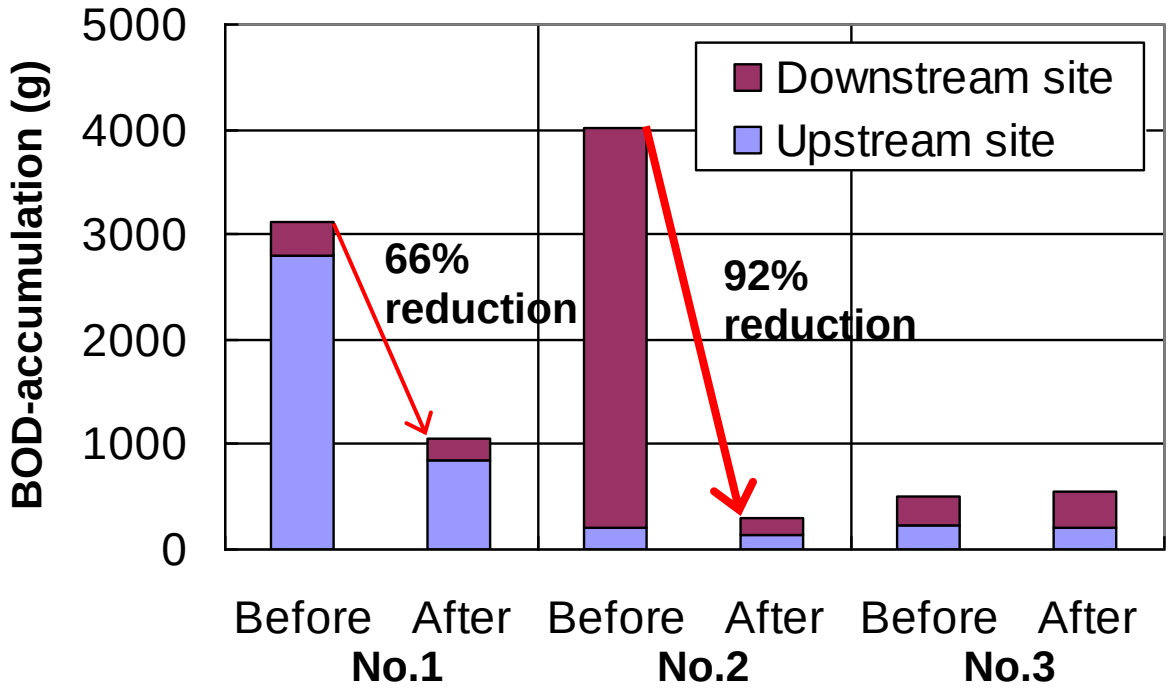
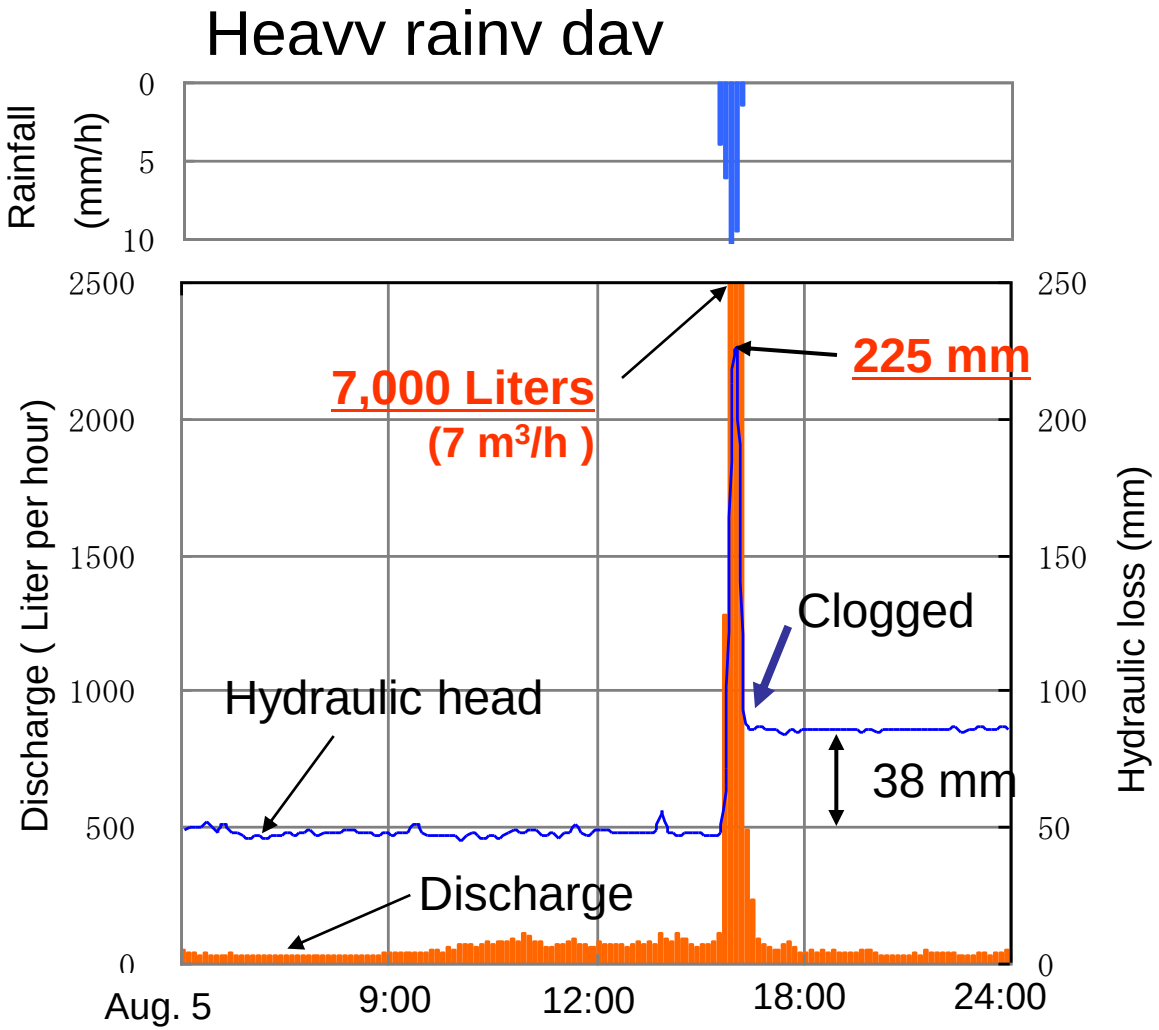


Fig. BOD in inverted siphons

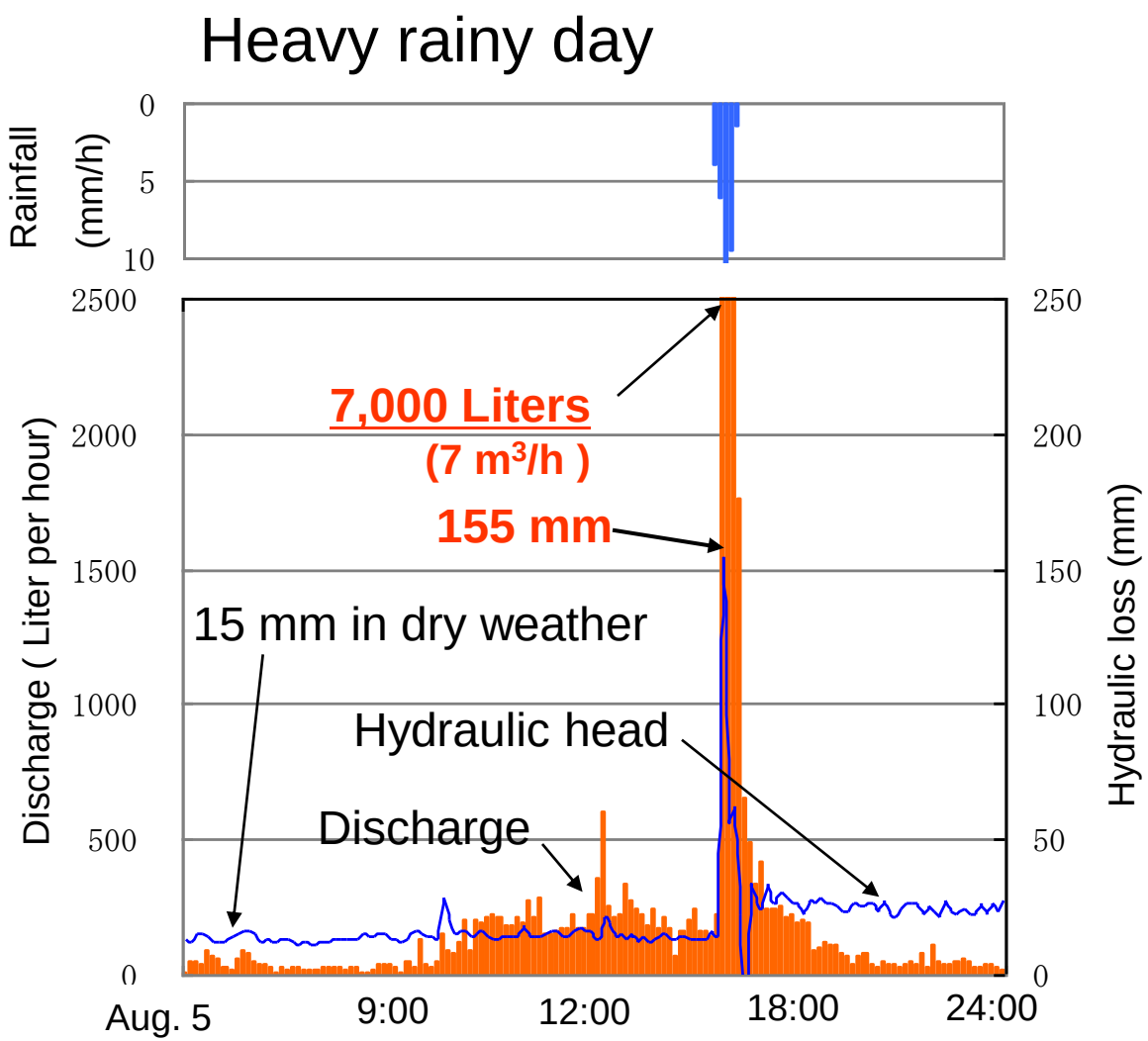
Results ~ Hydraulic head in heavy rainy day ~



- Increase of hydraulic head is 175 mm.
- Increase of Hydraulic head by tube's clogging is only 38 mm.

Fig. Discharge and hydraulic head in the No.1 inverted siphon

Results ~ Hydraulic head in normal inverted siphon ~



- Increase of hydraulic head is temporarily 140 mm in the inverted siphon without the device.
- Difference of hydraulic head with or without the device is about 35 mm.

Fig. Discharge and hydraulic head in the inverted siphon without the device

Summary

- This device can reduce in dry weather
  - BOD-accumulation: 66~92% reduction
  - Accumulation of sludge layer: 1/4
- Increase of hydraulic head caused by installing the device is
  - a few (=35 mm).
- Hydraulic head in inverted siphon is
  - 225 mm in the case of heavy rain, despite of 500 mm and over in experiment.

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