An integrated approach in flood prevention and water reclamation in a densely populated metropolitan: Will the innovation work?

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ABSTRACT

WHO[1] forecasted that half of the world's population would be living in water-stressed areas by 2025 due to climate change, population growth and urbanization. We therefore need to seize every opportunity to explore the water resource in carrying out drainage works. Exploring of water resource from local sources and water conservation is an essential strategy to maintain a reliable supply of fresh water. During the implementation of a flood alleviation scheme of constructing of an underground storage structure in a racecource, DSD has identified an opportunity to integrate a water harvesting system into an underground stormwater storage scheme

The Drainage Services Department (DSD) of the Hong Kong Special Administrative Region (HKSAR) is implementing the Happy Valley Underground Stormwater Storage Scheme (HVUSSS), comprising an underground storage tank within the Happy Valley Recreation Ground (HVRG) and associated drainage works, to enhance flood protection for the northern part of Hong Kong Island.

The construction of an underground stormwater storage tank provides an opportunity for implementing a system for harvesting water from groundwater pumped from the sub-soil drainage blanket under the foundation of the storage tank, and from irrigation and rainwater gathered from the sports grounds above the tank.

This water harvesting system consists of storage and pumping systems that gather and convey the harvested water via an underground pipeline system to a water treatment facility for appropriate treatment. The reclaimed water will be used for on-site irrigation at HVRG and for toilet flushing. This water reclamation is a means of gathering and reusing water, thus providing an effective and sustainable method of conserving scarce water resources in Hong Kong. It is also a pilot scheme to research the actual treatment cost for stormwater, which will be an important reference for future policy decision in this aspect.

1. INTRODUCTION

Less than 1% of fresh water resource is accessible at the surface in the forms of lakes and rivers on earth. Most of the fresh water resource is inaccessible at the surface such as glaciers and groundwater.

WHO[1] forecasted that half of the world's population would be living in water-stressed areas by 2025 due to climate change, population growth and urbanization. We therefore need to seize every opportunity to explore the water resource in carrying out drainage works. In United States, the United States Environmental Protection Agency has just released a guide "Enhancing Sustainable Communities with Green Infrastructure" [2]which aims to help communities to manage the stormwater better.

Hong Kong is a densely populated metropolitan, about 80% of fresh water supply is imported from mainland China in which water demand is also very high as a result of the recent industrial development. Exploring of water resource from local sources and water conservation is an essential strategy to maintain a reliable supply of fresh water. During the implementation of a flood alleviation scheme of constructing of an underground storage structure in a racecource, DSD has identified an opportunity to integrate a water harvesting system into an underground stormwater storage scheme.

2. BACKGROUND OF THE PROJECT

During the heavy rainfall events in August 2000, April 2006 and June 2008, severe flooding occurred at Happy Valley and adjacent areas. To relieve the flooding hazards of the Happy Valley catchment, the HKSAR has commissioned three major flood relief projects in the northern Hong Kong Island:

1. Upstream interception – Hong Kong West Drainage Tunnel
2. Midstream flood retention – Happy Valley Underground Stormwater Storage Scheme
3. Downstream upgrading – Lower Catchment Drainage Improvement Works

Previous drainage projects such as Tai Hang Tung Stormwater Storage Scheme and Sheung Wan Stormwater Pumping Station demonstrate that flood retention schemes are successful to alleviate flooding problems in urban low-lying areas with minimum public nuisances. As such, the DSD decided to implement an underground stormwater storage scheme in Happy Valley, which comprises construction of an underground stormwater storage tank (USST) underneath the Happy Valley Recreation Ground (HVRG to temporarily store part of the stormwater during excessive rainstorm events such that the peak flow in the downstream drainage system would be reduced. The stormwater temporarily stored in the USST will be discharged by pumps and gravity flow into the adjacent drainage box culvert. The scheme would reduce the flooding risk in the low-lying areas in Wan Chai and Happy Valley.

3. WATER RECLAMATION SCHEME ADOPTING THREE RAW WATER SOURCES

The USST being constructed underneath HVRG with 60,000 cu-m storage capacity will be the third stormwater storage tank in Hong Kong. The storage volume is equivalent to 24 standard size swimming pools. In the implementation of HVUSSS, various sources of raw water were identified for water reuse.

i) Groundwater

The conforming design of the foundation of the USST comprises 533 socketed pre-bored H-piles embedded into the bed rock to resist the buoyancy force acting on the USST. The construction cost is relatively high and it will cause various nuisances to the public. Therefore, the project team conducted an innovative design enhancement on the foundation design. Under the innovative design, the USST sat on a shallow raft foundation with sub-soil drainage layer surrounding the whole USST. With continuous drawdown of the water table by pumping the groundwater, it will reduce the flotation force and hence the need of pre-bored H-piles. A groundwater cutoff wall is built around the USST to control the seepage rate of groundwater into the raft foundation. Sub-soil drainage system is installed underneath the USST to convey groundwater to the sump pit for relief of buoyancy of tank.

ii) Irrigation water and rainwater harvested from sport pitches

Taking into account the extensive coverage of plan area (22,000 sq-m) of storage tank under sport pitches, collection of rainwater and irrigation water from sport pitches via sub-soil drainage system laying on top of storage tank is ready available.

iii) Stormwater collected from USST

Stormwater from upstream drainage system will be collected for temporary storage in the USST. However, the quantity of stormwater collected is unsteady and varies seasonally. The quality of the runoff in an urban area is generally not good for reuse, but the runoff from the later portion of a heavy rainfall may be much cleaner and may worth being treated for reuse purpose.

Taking into account the available sources of raw water for reuse, DSD engaged a Consultant, to conduct a feasibility study on water reclamation system under HVUSSS. In addition, to steer the research of this water reclamation scheme, a multi-disciplinary joint Task Force comprised members of DSD and Water Supplies Department (WSD), civil engineers, electrical and mechanical engineers, chemist and environmental protection officer is formed to monitor and develop the treatment technology and collect cost data on reuse of both underground water and stromwater collected.

In this study, key elements including water quality of various sources, water quality requirement of the intended use, demand and supply of the reclaimed water, stakeholders consideration for acceptance of the reclaimed water, reliability of supply, operation and maintenance (O&M) issues were identified which should be reviewed during planning and design stage.

3.1 Quality of Raw Water & Treated Water Quality Standard

Before conduction of sampling works, current and past land usage should be examined to assess the potential land contamination which results in the determination of testing parameters for analysis. The determination of testing parameters is not only affected by land use, but also the treated water quality standard.

Under formulation of treated water quality standard, intended usage should be clearly identified. The most ready available demand should be found within the site as it could largely reduce capital and O&M cost on additional pumping and pipeline system. In HVRG equipped with 11 nos. of sport pitches, a considerable amount of fresh water is required for irrigation and toilet flushing. The estimated weekly water demand for irrigation and toilet flushing is up to 4,150 cu-m. This extensive demand for fresh water matches with the anticipated production rate of water reclamation system. The proposed water quality standards summarized in Table 1 below are compiled from international practices as well as advice from the WSD for the intended non-potable uses. This standard would be used as the reference in the selection of appropriate treatment processes for the water reclamation.

Table 1 Recommended Water Quality Standards for the Water Harvesting Scheme in Happy Valley

Parameter	**Unit**	**Recommended water quality standards**
E. coli	No. /100 ml	Non-detectable
Total residual chlorine	mg/l	> 1 out of treatment system; > 0.2 at user end
Dissolved oxygen	mg/l	≥ 2
Total suspended solids (TSS)	mg/l	≤ 5
Colour	Hazen unit	≤ 20
Turbidity	NTU	≤ 5
pH		6 - 9
Threshold Odour Number (TON)		≤ 100
5-day Biochemical oxygen demand (BOD_5)	mg/l	≤ 10
Ammoniacal nitrogen	mg/l as N	≤ 1
Synthetic detergents	mg/l	≤ 5

Notes:
1. Apart from total residual chlorine which has been specified, the water quality standards for all parameters shall be applied at the point-of-use of the system.
2. Where recycled water is treated for immediate usage, the level of total residual chlorine may be lower than the one specified in this table.
3. Immediate usage means the collected stormwater/ rainwater is drawn into the treatment process immediately before a particular round of usage and the treated water will be depleted after that round of usage is completed.

3.1.1 Groundwater Quality

The site area, HVRG, is a reclaimed marshland which had been developed for recreational use, there is no potential risk on land contamination. Therefore, testing was conducted with reference to the proposed treated water quality standard. 3 nos. of samples of groundwater were taken at the site of HVUSSS in June 2013. The results revealed that the quality of groundwater satisfied the water quality requirements as stated in Table 1 except the requirement for total residual chlorine and the test results were summarized in Table 2 below. This implies that only disinfection dosage is needed to boost the residual chlorine level of groundwater before it is supplied for uses.

Table 2 Summary of Test Results for Groundwater

Parameter	Unit	Recommended water quality standards	SAMPLE 1 07-JUN-2013 15:45	SAMPLE 2 08-JUN-2013 09:15	SAMPLE 3 10-JUN-2013 15:10
E. coli	CFU/100 mL	Non-detectable	Not Detected	Not Detected	Not Detected
Total Residual Chlorine	mg/L	> 0.2	< 0.2	< 0.2	< 0.2
Dissolved Oxygen	mg/L	≥ 2	> 6.0	> 6.0	> 8.1
Suspended Solids (SS)	mg/L	≤ 5	< 2	< 2	< 2
Colour (Apparent)	CU	≤ 20	< 2.5	< 2.5	< 2.5
Turbidity	NTU	≤ 5	< 1	< 1	< 1
pH Value	pH Unit	6 - 9	6.0	6.0	6.5
Threshold Odour Number (TON)	TON	≤ 100	< 1	< 1	< 1
Biochemical Oxygen Demand	mg/L	≤ 10	< 2	< 2	< 2
Ammonia as N	mg/L	≤ 1	0.03	0.01	0.01
Total Surfactants	mg/L	≤ 5	< 1.0	< 1.0	< 1.0

3.1.2 Quality of irrigation water and rainwater harvested from sport pitches

The sub-soil drainage system underneath sport pitches is a layer of filter which would achieve the performance of coarse screening. Also, the source of irrigation water and rainwater is pure, the concentration of parameter such as total suspended solid and turbidity is minimal. Disinfection is recommended, in case the quality would not satisfy with the recommended standard, simple filtration system such as sand filter could be adopted.

3.1.3 Stormwater Quality

5 nos. of samples of stormwater were taken from existing box culvert underneath Wong Nai Chung Road in August 2013. From the sampling test results, it was revealed that other than high total suspended solid (up to 180 mg/l) and turbidity (a figure of 66 NTU was recorded), the other parameters such as colour, Biochemical Oxygen Demand (BOD) and microbiological aspects are outside the range of the required standard and therefore the harvested stormwater needs treatment before it can be utilized for non-potable uses. The treated stormwater shall also undergo a disinfection process for health and safety considerations. Summary of test results for stormwater at existing box culvert underneath Wong Nai Chung Road is shown in Table 2 below.

Table 2 Summary of Test Results for Stormwater

Parameter	Unit	Recommended water quality standards	SAMPLE 1 23-AUG-2013 14:00	SAMPLE 2 30-AUG-2013 09:20	SAMPLE 3 30-AUG-2013 09:35
E. coli	CFU/100 mL	Non-detectable	60,000	27,000	35,000
Total Residual Chlorine	mg/L	> 0.2	< 0.2	< 0.2	< 0.2
Dissolved Oxygen	mg/L	≥ 2	8.4	6.0	6.1
Suspended Solids (SS)	mg/L	≤ 5	180	37	32
Colour (Apparent)	CU	≤ 20	75.0	37.5	25.0
Turbidity	NTU	≤ 5	66	10	6
pH Value	pH Unit	6 - 9	7.3	7.1	7.1
Threshold Odour Number (TON)	TON	≤ 100	< 1	1	1
Biochemical Oxygen Demand	mg/L	≤ 10	8	12	9
Ammonia as N	mg/L	≤ 1	0.36	0.16	0.53
Total Surfactants	mg/L	≤ 5	< 1.0	< 1.0	< 1.0

Table 2 Summary of Test Results for Stormwater (Cont'd)

Parameter	Unit	Recommended water quality standards	SAMPLE 4 30-AUG-2013 09:50	SAMPLE 5 30-AUG-2013 10:05
E. coli	CFU/100 mL	Non-detectable	78,000	37,000
Total Residual Chlorine	mg/L	> 0.2	< 0.2	< 0.2
Dissolved Oxygen	mg/L	≥ 2	5.7	6.0
Suspended Solids (SS)	mg/L	≤ 5	38	32
Colour (Apparent)	CU	≤ 20	25.0	25.0
Turbidity	NTU	≤ 5	6	8
pH Value	pH Unit	6 - 9	7.1	6.9
Threshold Odour Number (TON)	TON	≤ 100	1	1
Biochemical Oxygen Demand	mg/L	≤ 10	11	10
Ammonia as N	mg/L	≤ 1	0.56	0.50
Total Surfactants	mg/L	≤ 5	< 1.0	< 1.0

3.2 Availability of Supply

The reliability and consistency of the supply are the major concerns on the design which would affect the storage requirement. Groundwater which varies seasonally would affect the influent quality and incur unsteady supply. The estimated quantity of groundwater supply is 500 cu-m/day.

For irrigation water collected from sport pitches on top of USST, the estimated quantity is about 100 cu-m/day taking into account the loss from absorption and evaporation. Under the estimation, the supply of groundwater and irrigation water from sport pitches could meet the water demand for irrigation and toilet flushing at HVRG.

In regard to stormwater, the difference in quantity collected between wet and dry seasons is very large resulting in significantly impaired the overall effectiveness. Since the stormwater stored for reclamation occupied the storage volume of USST for flood alleviation which results in depression of flood protection performance. Therefore, the spatial requirement and treatment rate should be designed carefully in order to strike a balance between flood protection standard and the supply quantity of stormwater. Having considered the unsteady supply of stormwater, limited space in HVRG and flood protection requirement, reuse of stormwater was proposed to be conducted under HVUSSS as a trial of 50 cu-m/day. Supplement of fresh water should also be provided for back up purpose.

3.3 Considerations on selection of treatment process

Spatial, O&M requirements would largely affect the selection of treatment technology. According to the water quality of the stormwater available from the test reports, the collected stormwater were generally high in both turbidity and suspended solids. Though these two parameters can be reduced through the settling of the stormwater in the storage tank before it is bled off for treatment, the occasional spikes should be taken for consideration in the selection of the treatment process. The conventional clarification and filtration treatment will be capable of producing final water to the requirements. However, since the site space is a constraint and therefore compact type treatment modules shall be considered.

Membrane filtration is a modern physicochemical separation technique that uses differences in permeability of the influent as a separation mechanism. During membrane treatment, the infeed water is pumped against the surface of a membrane, resulting in the production of product and waste stream. The product stream is relatively free of impermeable constituents and will have the targeted solids completely removed in conjunction with bacteria and protozoa-sized particles. The process is easily automated and the space requirements are much smaller than conventional plants.

There are two basic configurations of the membrane modules: pressurized/encased system and submerged system. Submerged system is capable of tolerating a wider range of turbidity spikes and it has substantially fewer valves and piping connections when compared with the pressurized system due to its flexibility to accommodate larger modules. Considering the water quality of the stormwater and the footprint available at the site, submerged membrane is proposed for the filtration process. To alleviate the fouling on the membrane and enhance the filtration performance of the system, a flocculation tank is also proposed as a pre-treatment option to the membrane system in case the stormwater is of adverse quality. The treatment process of the integrated water reclamation system is illustrated in Figure 1.

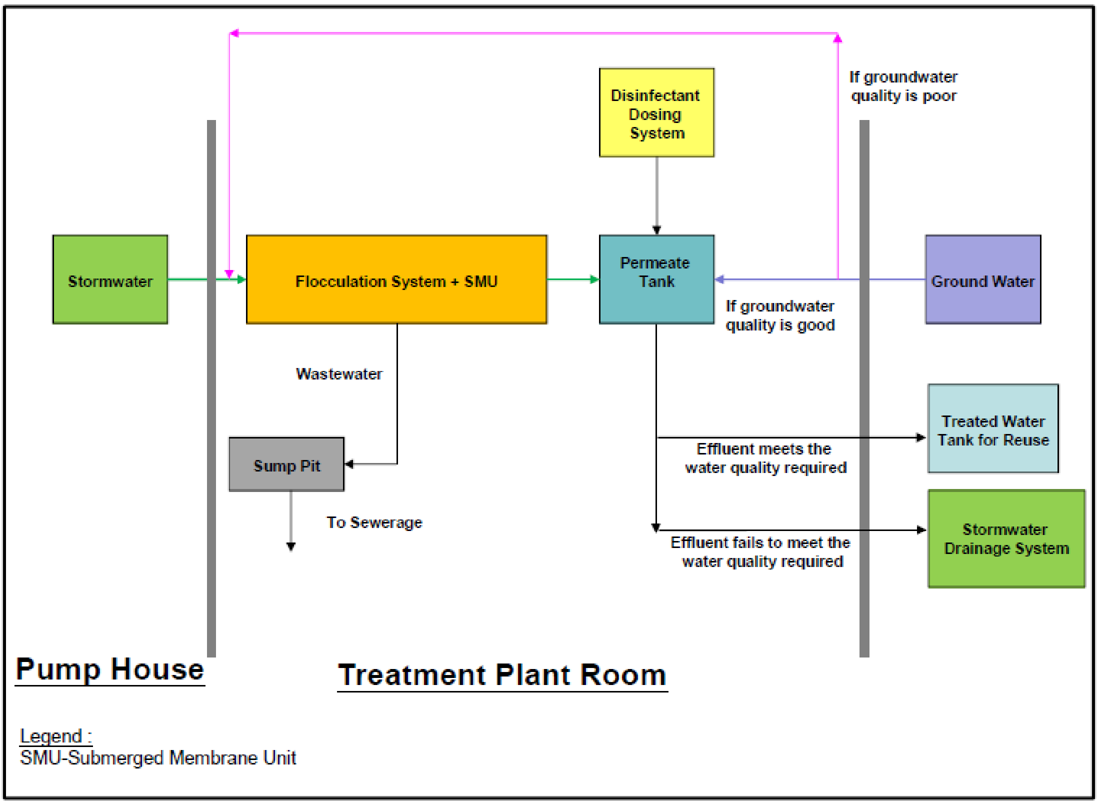

Figure 1: Treatment Process

3.4 Post-commissioning monitoring

In order to evaluate the performance of water reclamation system, operation and monitoring period is allowed for collection of information and relevant data. Information required is identified as below:

i) cost data on construction and O&M;
ii) O&M requirements such as maintenance frequency, details of repair works, routine cleaning works;
iii) quality and quantity of raw water and treated water

To facilitate the evaluation of performance, meters and sensors equipment, logbook and O&M manual should be incorporated in design stage. This valuable data is useful for recommendation on the further implementation of water reclamation system in other projects.

4. CONCLUSION

The vision of DSD is to provide world-class wastewater and stormwater drainage services enabling the sustainable development of Hong Kong. The use of effective water reclamation system is therefore of potential importance in providing alternative water sources and reducing fresh water demand. Fresh water consumption in the HVRG is mainly for irrigation of sport pitches and toilet flushing. The innovative foundation design will facilitate collection of a considerable amount of groundwater via the sub-soil drainage system. The large area at ground level within the footprint of USST will be used as reprovision of sport pitches and a landscaping area which also allows collection of rainwater and irrigation water. The above ready availability of water sources provides an advantage for promoting the rainwater harvesting system. In addition, it provides an opportunity to investigate the feasibility of reuse of stormwater from the existing drainage system which can increase the supply of reclaimed water for extensive fresh water demand at HVRG from LCSD and HKJC. The results of this research item will provide valuable information for the subsequent adoption of water reclamation system in other DSD's facilities or the public and private sectors, thus encouraging water reclamation and sustainable development under the support from

Advisory Committee on Water Resources and Quality of Water Supplies[3] and Task Force formulated between WSD and DSD.

References

[1] World Health Organization. http://www.who.int/en/
[2] United States Environmental Protection Agency (2014, October). *Enhancing Sustainable Communities with Green Infrastructure.* http://www.epa.gov/smartgrowth/green-infrastructure.html
[3] Advisory Committee on Water Resources and Quality of Water Supplies. http://www.wsd.gov.hk/acqws/en/welcome/index.html