A Cost-effective and Innovative Design of Effluent Tunnel and Disinfection System for the Harbour Area Treatment Scheme (HATS) Stage 2, Hong Kong

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Abstract
The effluent tunnel and disinfection system is an integral part of the Harbour Area Treatment Scheme (HATS) Stage 2A for effluent disposal and discharge licence compliance. The original scheme as proposed in the earlier phase of the study had adopted a conventional arrangement consisting of a short effluent tunnel, a large above-ground disinfection tank and connection culverts. After undertaking a value management (VM) exercise, an innovative alternative scheme which comprised an enlarged and lengthened effluent tunnel to provide sufficient retention time for disinfection was proposed, evaluated and adopted. This alternative scheme is an 8.5m diameter, 880m long effluent tunnel at 90m below ground, conveying the effluent from the Stonecutters Island Sewage Treatment Works (SCISTW) to the new flow chamber towards south-west of SCISTW, and connecting to the existing outfall drop shaft. Various advantages in landuse planning, environmental, operation & maintenance (O&M) and life cycle cost (LCC) could be achieved.

Keywords
Harbour Area Treatment Scheme; value management; effluent tunnel; disinfection; landuse planning; life cycle cost.

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INTRODUCTION
Harbour Area Treatment Scheme (HATS) is a major clean harbour project by providing a centralised sewage collection, treatment and disposal system for the highly urbanised areas on both sides of Victoria Harbour of Hong Kong, serving ultimately a population of 5.7 million. HATS Stage 1, treating 75% of sewage from Harbour area, was completed and put in full operation in 2001. Implementation of HATS Stage 2 (in two phases namely Stage 2A and Stage 2B) is now underway with construction of the Stage 2A works commenced since July 2009 for commissioning in end 2014. Upon commissioning of HATS 2A, all sewage from Harbour area will be treated before discharge into the Harbour.

In the HATS Stage 2A design, innovation, cost-effectiveness and sustainability have been considered and introduced in various dimensions, in view of the scale of the project. Value management (VM) has been adopted during the planning and early design stage as an effective tool to meeting the design requirements of HATS Stage 2A while achieving “value for money” at the lowest whole life cycle cost. This paper illustrates how such approach has been reflected in the integrated system of effluent disposal and disinfection to be provided under HATS Stage 2A.
PLANNING, DESIGN AND VALUE MANAGEMENT

One of the major components of HATS Stage 2A is to expand the existing Stonecutters Island Sewage Treatment Works (SCISTW) to cater for the additional sewage collected from the HATS catchment. In addition, disinfection facility will be installed to substantially reduce the bacteria levels of the effluent. The design flows are 2.44 million m$^3$/day under average dry weather flow (ADWF) condition and 4.1 million m$^3$/day under peak flow condition.

Under the existing HATS Stage 1 effluent disposal system, all treated effluent is conveyed by a twin-cell box culvert from SCISTW to the submarine outfall for discharging into the Harbour. To cope with the additional flow, an effluent disposal system with sufficient hydraulic capacity for the combined HATS Stages 1 and 2A flow would be provided. In view of various site constraints, expansion of or modification to the live twin-cell box culverts would not be feasible. The option of constructing a new effluent disposal system integrated with disinfection facility was identified and developed with the following two components.

**Effluent Tunnel:** In order to overcome the landuse and highways/drainage structure foundation constraints in the vicinity, deep tunnel is the preferred option for effluent disposal. Similar system has been adopted in HATS Stage 1, given various benefits of minimised disturbance to public, traffic flow, underground utilities and constraints to future land developments. The sewage tunnel is to be constructed in rock with a minimum 30m bed rock cover in accordance with local statutory requirement.

**Disinfection Facility:** Chlorination and dechlorination has been selected for HATS Stage 2A as the effluent disinfection process. A typical chlorination and dechlorination facility would normally consist of chemical storage tanks, dosing units, contact tank and control & monitoring system. A design chlorination process (using sodium hypochlorite) of at least 30 minutes contact time during the ADWF condition and at least 20 minutes during the peak flow condition is adopted for HATS Stage 2A, targeting to achieve a minimum 3-log (i.e. at least 99.9%) removal of *E. Coli* under all planned design flow scenarios. After chlorination, the dechlorination chemical (using sodium bisulphite) will be added to remove any residual chlorine, before the disinfected effluent is conveyed to the existing outfall drop shaft and then to the Harbour.

**Features of Original Scheme**

In the original scheme of effluent disposal and disinfection facility system developed during the engineering feasibility stage, the effluent will be chlorinated at the flow distribution chamber (FDC) within the existing SCISTW and then conveyed to the chlorine contact tank by the effluent tunnel. After achieving sufficient chlorine contact time, the disinfected effluent will then be dechlorinated before discharging into the existing submarine outfall via the connection culvert and flow chamber (Chamber 15A). This original scheme would involve the construction of an effluent tunnel of approximately 460m long, 7m diameter and 90m below ground, a large above-ground chlorine contact tank (174m$^2$x34m footprint), dechlorination facilities, a 300m long connection culvert and a flow chamber connecting to the existing outfall drop shaft.

The layout plan of the scheme is presented in **Figure 1** and the sectional schematic is presented in **Figure 2**. This scheme, if proceed, would satisfy the engineering requirements for the necessary chlorine contact process, dechlorination and effluent disposal. The downsides of this scheme, however, are landuse planning and environmental issues as described below.

**Landuse Planning Issues:** Land is a precious resource in Hong Kong. The proposed chlorine contact tank and dechlorination facility is located at a piece of approximately 4ha vacant land, which is
reserved for container-related landuse such as parking area for goods vehicles and container trailers/tractors, loading/unloading facilities, container storage and repairs, public cargo working areas and mid-stream operations, among others under the outline zoning plan for Stonecutters Island. Locating the proposed chlorine contact tank and dechlorination facility in the vacant land would restrict the future landuse and development potential of the vacant land. Moreover, statutory procedures for the proposed rezoning exercise would be necessary which would likely face strong objections by the affected stakeholders, resulting in potential impacts on HATS Stage 2A implementation.

**Environmental Issues:** Unless the treated effluent flow is either (i) entirely under surcharge condition or (ii) lifted via transfer pumping arrangement, the top water level of the chlorine contact tank must lie between the upstream and downstream flow chamber invert levels which is approximately 2-3m above the existing ground level. The contact tank height would thus be some 3-4m above ground level and have an overall water depth of some 14m with approx. 11m below ground level. The environmental impacts arising include construction noise and dust, spoil disposal, odour, fixed operational plant noise, and visual impact, which all require considerable effort to mitigate in order to reduce the associated impact on neighbouring sensitive receivers to acceptable level.

![Figure 1. Layout Plan of Original Effluent Tunnel and Disinfection System.](image1)

![Figure 2. Schematic of Original Effluent Tunnel and Disinfection System.](image2)

Key:
1. FDC Extension
2. Effluent Tunnel
3. Chlorine Contact Tank
4. Connection Culvert
5. New Flow Chamber 15A
Use of Value Management Approach and Features of Alternative Scheme

Identifying the above project risks and re-visiting the fundamental engineering requirements of the system, a number of alternative and innovative approaches have been derived during a VM workshop where all project stakeholders brainstormed and studied the acceptability, practicality and cost-effectiveness of these approaches. An alternative scheme of integrating the effluent disposal system and disinfection facility was proposed to replace the original one.

This alternative scheme consists of an 8.5m diameter, 880m long deep effluent tunnel at 90m below ground, which will convey the effluent directly to the existing outfall drop shaft. The enlarged effluent tunnel diameter aims to provide the sufficient contact time within the effluent tunnel for effective chlorination. The dechlorination dosing, control & monitoring systems can be installed in the existing flow chamber site downstream of the effluent tunnel. The layout plan of the alternative scheme is presented in Figure 3 and the sectional schematic is presented in Figure 4. The application of chlorination process within a large diameter deep tunnel with capacity over 2 million m³/day is probably the first of this kind globally.

Through this scheme, the need for a large above-ground chlorine contact tank and the connection culvert could be eliminated which could bring considerable benefits from landuse planning, environmental, operation & maintenance (O&M) and life cycle cost (LCC) perspectives, as described in the next section of this paper.

Key:
1. FDC Extension
2. Effluent Tunnel
3. New Flow Chamber 15A

Figure 3. Layout Plan of Alternative Effluent Tunnel and Disinfection System.

Figure 4. Schematic of Alternative Effluent Tunnel and Disinfection System.
BENEFITS OF THE ALTERNATIVE SCHEME

The comparative features of the original and alternative schemes of effluent tunnel and disinfection facility are summarised in Table 1. Upon further discussion and deliberation with project stakeholders, the alternative scheme is adopted for implementation in HATS Stage 2A.

Table 1. Original and Alternative Schemes of Effluent Tunnel and Disinfection System.

<table>
<thead>
<tr>
<th>Option</th>
<th>Original Scheme</th>
<th>Alternative Scheme</th>
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</table>
| Common Features | ❖ Effluent Disposal: from SCISTW to existing outfall drop shaft  
❖ Drop Shaft and Riser Shaft: 90m deep each  
❖ New Flow Chamber (Chamber 15A): near existing outfall drop shaft  
❖ Minimum Chlorine Contact Time: 30 minutes (ADWF), 20 minutes (peak) | ❖ Deep Tunnel  
7m dia, 460m long, 90m deep  
❖ Above-ground chlorine contact tank  
174m x 34m x 14m deep  
❖ Connection to new flow chamber  
Twin-box culvert, some 300m long                                                                 |
| Distinctive Features | ❖ Deep Tunnel  
8.5m dia, 880m long, 90m deep  
❖ Above-ground chlorine contact tank Eliminated  
❖ Connection to new flow chamber Deep tunnel                                                                 | ❖ Deep Tunnel  
❖ Above-ground chlorine contact tank Eliminated  
❖ Connection to new flow chamber Deep tunnel                                                                 |
| Disinfection | Achieved both along effluent tunnel and at chlorine contact tank                                                                                                                                          |Achieved along deep effluent tunnel                                               |

Landuse Planning Merits

**Permanent Landuse.** Among other things, the alternative will bring benefits such as minimizing land intake and avoiding designation of additional drainage reserve for the proposed effluent culvert. Since the entire effluent tunnel will be constructed deep underground, the original land required for the large above-ground chlorine contact tank can be released for other purposes or intended uses. As the effluent tunnel will be constructed with adequate bed rock cover, any future development scheme of the site will not be restricted.

**Temporary Landuse.** Since the vacant land is close to SCISTW, it is now ideally utilised for the HATS Stage 2A project on a short-term basis for site offices and storage area for construction materials. The merits are specifically (i) to alleviate the congestion issue within SCISTW during the concurrent plant upgrading works required for HATS Stage 2A and (ii) to allow timely construction of HATS Stage 2A.

Environmental Merits

**Air Quality and Noise.** The original scheme with significant above-ground structure has been adopted for the environmental impact assessment (EIA) study for HATS Stage 2A which demonstrates that the predicted performance of the proposed facility, in terms of air quality and noise during construction and operation stages, would comply with the respective requirements under the technical memorandum for environmental impact assessment process provided proper environmental mitigation measures are put in place. Given the alternative scheme being located deep underground, the associated impacts will be less than those of the original scheme, resulting in better environmental performance in terms of air quality and noise.

**Odour.** The above ground chlorine contact tank could be a potential odour source during the operational phase. With the deletion of the tank, the disinfection process will be completed inside the effluent tunnel, thus the potential odour liberation would be greatly reduced and become
insignificant. In addition, since a surcharge flow condition is maintained along the effluent tunnel, no head space exist (in contrary for the original scheme) such that much reduced air volume would need to be deodorised, leading to savings in deodorisation operation. Reduced deodorisation requirement will also lead to lower chemical consumption and storage requirements, thus a lower hazard-to-life level.

**Visual.** Another environmental merit is the elimination of visual impact due to the large above-ground chlorine contact tank.

**Construction & Demolition Material (C&DM).** The total bulk volume of soil generated from the construction of chlorine contact tank and effluent culvert was estimated to be about 117,000m$^3$. As it is proposed to delete the above ground chlorine contact tank and the connection culvert, the alternative scheme will bring about benefits in terms of waste management by minimizing the generation of soil material, and thus preserve the valuable space in the existing fill banks. On the other hand, the alternative scheme presents advantages in more valuable/useable granitic rock recovery for re-processing as aggregate (**Table 2** refers).

**Table 2.** C&DM Generation from Original and Alternative Schemes of Effluent Tunnel and Disinfection System.

<table>
<thead>
<tr>
<th>C&amp;DM Generation (in-situ)</th>
<th>Original Scheme</th>
<th>Alternative Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel/Connection Box Culverts</td>
<td>51,538m$^3$</td>
<td>71,588m$^3$</td>
</tr>
<tr>
<td>Drop and Riser Shafts</td>
<td>9,614m$^3$</td>
<td>9,614m$^3$</td>
</tr>
<tr>
<td>Chlorination Contact Tanks</td>
<td>55,593m$^3$</td>
<td>-</td>
</tr>
<tr>
<td>Total C&amp;DM</td>
<td>116,745m$^3$</td>
<td>81,202m$^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-35,543m$^3$ or 30.4% lower)</td>
</tr>
<tr>
<td>Granitic Rock (% of Total C&amp;DM)</td>
<td>61,420m$^3$ (52.6%)</td>
<td>78,375m$^3$ (96.5%)</td>
</tr>
</tbody>
</table>

**Operation & Maintenance (O&M) Merits**

Various engineering aspects including treatment process, hydraulic, geotechnical, traffic and constructability have been evaluated and are considered similar for both schemes. The major engineering merits of the alternative scheme are derived from the O&M considerations.

From operation perspective, since an intermediate chlorine contact tank is no longer required, there would be fewer instruments, mechanical plants and isolation penstock/valves/sluice gates needing manual operation, resulting in reduced workload of plant operators. The prime focus of the system operation would be flow-paced chemical dosing, residual chlorine level and flow chamber level monitoring, which are automated and programmed in the control and monitoring systems.

The effluent tunnel is designed as an inverted siphon where the linear velocity of effluent shall be maintained above the self-cleansing velocity to avoid sediment deposition within the horizontal section of the deep effluent tunnel. Even under the tunnel diameter of 8.5m and at initial years of HATS Stage 2A operation where the design ADWF will yet be built up (i.e. at 2.02 million m$^3$/day or 23.39m$^3$/s), the effluent linear velocity would be kept above 0.41m/s which is sufficient to keep the fine sediment particles in suspension. In other words, the scheme is designed and operated as a
maintenance-free effluent tunnel. Only periodic review of hydraulic performance, similar to those for the deep sewage tunnels in HATS Stage 1 system, is envisaged.

**Life Cycle Cost (LCC) Merits**
The two main components of LCC are capital cost and O&M cost. The serviceable life of the system over a period of 50 years and a 4% per annum discount factor are adopted to derive the total cost in a net present value (NPV), which can facilitate the cost comparison between different options. For the cases of original and alternative schemes, the main LCC components and respective NPVs are presented in Table 3 below. The alternative scheme could potentially bring a HKD259 million savings in NPV (or approximately 38% advantage in the LCC) over that of the original scheme. Significant portion of the potential savings could be achieved over the initial years of the life cycle, during the construction of the system.

**Table 3. Life Cycle Cost Evaluation between Original and Alternative Schemes of Effluent Tunnel and Disinfection System.**

<table>
<thead>
<tr>
<th>Life Cycle Cost Components</th>
<th>Original Scheme</th>
<th>Alternative Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost (2009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>HKD 604 million</td>
<td>HKD 383 million</td>
</tr>
<tr>
<td>Civil components</td>
<td>HKD 575 million</td>
<td>HKD 369 million</td>
</tr>
<tr>
<td>E&amp;M components</td>
<td>HKD 29 million</td>
<td>HKD 15 million</td>
</tr>
<tr>
<td>Annual O&amp;M Cost</td>
<td>HKD 1.46 million</td>
<td>HKD 0.73 million</td>
</tr>
<tr>
<td>NPV over the serviceable life of the system (2009)</td>
<td><strong>HKD 679 million</strong></td>
<td><strong>HKD 420 million</strong> (-38%)</td>
</tr>
</tbody>
</table>

**THE WAY FORWARD**
Construction of the alternative system commenced in June 2011 to cope with the overall HATS Stage 2A commissioning in end 2014. As discussed above, there are a number of merits of the alternative scheme of the effluent tunnel and disinfection system over the original one. Some attributes of the alternative scheme, however, are identified as follows for close monitoring and follow-up.

_Disinfection Performance_. The effluent tunnel is essentially a long narrow structure resembling plug flow condition. To ensure effective chlorine contact, complete mixing of treated effluent with chlorine shall be achieved prior to entering the effluent tunnel. Chemical dosing at the upstream FDC under turbulent flow condition is required. Proper dosing unit and mixing arrangement shall be implemented and optimised on site during construction and commissioning.

_Inherent Construction Risk_. Tunnelling especially at great depth is an inherently risky construction activity that can pose considerable potential of loss of life and damage to property such as collapse, explosion, flooding, fall from height, toxic gas poisoning and asphyxiation, among others. Proper construction activities planning, risk mitigation, specific site safety system and adequate site supervision shall be implemented.

_Future Operation_. The issue of inaccessibility to the deep effluent tunnel, in contrary to the above-ground facilities with proper accessibility, has been flagged up by the project team. Proper material and hydraulic designs of the effluent tunnel have been performed and critically reviewed before
acceptance for construction. In addition, proper O&M measures such as maintaining self-cleansing velocity and periodic tunnel flushing are being considered and incorporated in the future O&M strategy of the system.

SUMMARY
The case study of an innovative effluent tunnel and disinfection system design illustrates the importance and potential benefits brought by the VM approach, group discussion and brainstorming that could bring innovative, cost-effective, environmentally-friendly and optimised solutions while satisfying the engineering requirements for this essential element of the HATS Stage 2A works.

The major sewerage infrastructure is under full steam construction, targeting for overall system commissioning in 2014/15. HATS Stage 2A will bring further improvement to the marine water quality in Victoria Harbour, marking a major milestone towards sustainable development of Hong Kong.

REFERENCES
Drainage Services Department (June 2002), Research & Development No. RD1006 - A review of Three Existing Sewage Tunnels and Recommendations on the Guidelines for Tunnel Design with respect to Future Tunnel Maintenance and Inspection.
Harry Lee, David Pickles, Fergal Whyte, Lawrence Ho, Henry Chau (2011) Main Sewage Pumping Station for the Harbour Area Treatment Scheme (HATS) Stage 2, Hong Kong SAR - A Case Study. The 4th IWA-ASPIRE Conference and Exhibition, Tokyo, Japan, 2-6 October 2011.
Ove Arup & Partners Hong Kong Ltd (March 2009), Construction and Demolition Material Management Plan.
Ove Arup & Partners Hong Kong Ltd (December 2009), S16 Planning Application – Planning Statement for the Proposed Extension of Drainage Chamber and Culvert at Container Port Road South, Stonecutters Island, Kwai Chung.