Operating Experience of Inflatable Dam for Pollution Control in Deep Bay, Hong Kong

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ABSTRACT: Inflatable dams have been adopted for pollution control in urban streams in Hong Kong. The dams have served the purpose satisfactorily by preventing organic suspended particles from the polluted tidal backflow entering the streams in which odor is generated when these organic pollutants are decomposed under anaerobic condition at the bottom of the stream. With an automatic deflation response to an increase in flow rates under a heavy rainfall, the dams do not pose higher flooding risk to the community.

In recent years, there is a paradigm shift in stormwater management in which more focus is placed on eco-hydraulics and low carbon footprint (Wenger et al., 2009; Brown and Farrelly, 2008). Therefore, it is time to review the need and the operation mode of these inflatable dams so that the operation not only meets the objective of pollution control, but also enhances the ecological value of the stream and reduces energy consumption. As measures for achieving these multiple targets are sometimes contradictory, it is not easy to reach the right balance which is dynamic in nature and also site specific, with limited information on flow, ecology, and pollution loading.

This paper presents a review of the operating experience of three inflatable dams in urban streams, namely the Yuen Long Bypass Floodway (YLBF), Ngau Tam Mei Nullah (NTMN) and Yuen Long Nullah (YTN). Although they are very close to each other and discharge into the same estuary, Deep Bay in Hong Kong, the site specific conditions would affect the need and the operation of the dam. The YLBF is an engineered channel to divert upstream runoff away from Yuen Long town center for flood prevention. For the purpose of energy saving, the frequency on dam deflation and bypass pumping has been reduced. It satisfactorily achieved annual electricity saving of 100,000kWh, and thus corresponding 70tCO₂e emission. The inflatable dam for the NTMN was damaged incidentally a few years ago and it was beyond repair. The broken dam, however, has re-established the connection between the stream and the bay, and thus enhancing the ecological value of the stream. Lastly, the YLN running through the Yuen Long town centre is a candidate for revitalization of urban stream for the community. The findings of a detailed investigation with stakeholder engagement suggest that only a section of the nullah in the town center could be revitalized at this stage, and the existing inflatable dam should be maintained to prevent the pollution from Deep Bay.

KEY WORDS: Stormwater management, Eco-hydraulics, Pollution control, Inflatable dam, Deep Bay
INTRODUCTION

Dam affects ecology of stream but it brings a lot of benefits to human beings such as flood mitigation, water storage for potable use and irrigation, power generation and navigation, etc. (Gao, 2007; America Rivers, 2002a). Mass infrastructural dam projects are always considered as a symbol of development and progress including Three Gorges Dam in China, Bhakara and Hirakud Dams in India, Aswan Dam in Egypt and Bakun Dam in Malaysia, etc. (Choy, 2004; Sahin and Kurum, 2002). In Hong Kong, large dams were constructed primarily for impounding reservoirs, and dams in streams are relatively small. These small dams or weirs were mainly built for agricultural purposes in the 1960s’, and many inflatable dams were built to replace agricultural weirs in the early 1990s’. They have a deflation function which is an advantage as flood mitigation devices when compared to concrete weirs (Tam, 1998, 1998a). When pollution problems received much attention in the 1990’s, inflatable dams were also designed and installed as tidal barrier for preventing polluted water with many organic suspended particles from entering the urban stream. These organic pollutants settled at the bottom of the stream would decompose under anaerobic condition and cause odor nuisance. Yuen Long Nullah (YLN), Ngau Tam Mei Nullah (NTMN) and Yuen Long Bypass Floodway (YLBF) are three examples located in the catchments of Deep Bay with inflatable dams built in 1992, 2004 and 2006 respectively for pollution control (DSD, 2010).

Revitalization of urban streams, either an ambitious river restoration target to return a river to its natural and ecological functions before disturbance, or a less ambitious concept in rehabilitating a river in trying to balance the revitalization of the ecological, geological, hydrological and social functions of a stream running through a urban setting (ESCAP, 2010), has been a popular topic in developed countries worldwide. Contemporary water body restoration guidelines produced by the USA’s Federal Energy Regulatory Commission (FERC), the European Union’s Water Framework Directive (WFD), the United Nations Economic and Social Commission for Asia, the Asian River Restoration Network, Singapore’s Public Utilities Board’s (PUB) Active, Beautiful, Clean (ABC) Waters Programme, and Korean Cheong Gye Cheon project, etc. are noted in recent decade (DSD, 2013; Bednaerk, 2001). This suggests a paradigm shift in urban stream management solely from its engineering functions and economical benefits to eco-hydraulics and societal impacts (Wenger et al., 2009; Brown and Farrelly, 2008; America Rivers, 2002a). Incorporation of environmental management/operation approach or even removal of dam to fix the problem of natural environmental deterioration of many river basins or enhance its ecologic values has been discussed in different context (America Rivers, 2002a; Bednaerk, 2001). The policy of USA FERC to mandate the incorporation of environmental management/operation measures to improve the river ecology through its relicensing process for hydropower operations, e.g. utility companies, municipalities and independent power producers, is an example. The mandated new operation conditions under the new license includes an increase in minimum flows, provision of or improvement on fish ladders, and periodic high flows and protection measures for riparian land, etc., are added in the relicensing conditions (Bednaerk, 2001).

Similar measures for stream rehabilitation have been implemented in Singapore since the 1970s’ (Joshi, 2012; Chou, 1998) to solve the severe pollution problem in the Singapore River, under the Singapore River and Kallang Basin Clean-up Programme. It eventually led to the PUB's ABC Waters Programme in 2006, a strategic initiative to improve the quality of water and life by harnessing the full potential of the water bodies. PUB adopts different ABC Water design features, or commonly known as stormwater best management practices (BMP) e.g. rain gardens, bioretention swales and wetlands to improve existing storm drain systems in order to regulate flows as well as to treat runoff onsite to prevent polluted discharge into downstream rivers or reservoirs, and also enhances the surroundings with biodiversity and aesthetic values (PUB, 2011). Of which, flood control and public health risk (e.g. mosquito breeding) are two key engineering and societal considerations in addition to environmental enhancement when implementing the ACB Waters Programme. Some ABC Waters projects also de-channelize the concrete drainage into a meandering natural river with soft and lush riverbanks without scarifying its flooding control capacity, e.g. the Kallang River at Bishan Ang Mo Kio Park. Similar stream rehabilitation
programme is also observed in Seoul, Korea, of which Cheong Gye Cheon has been successfully rehabilitated from an underground box culvert to an urban stream with clean water and natural habitats for fish, birds, and insects. The stream also helped to cool down the temperature on the nearby areas by 3.6 °C on average versus other parts of Seoul. Cheong Gye Cheon becomes a centre for cultural and economic activities in Seoul, and also a popular tourist spot of Seoul (DSD, 2013; OSCT; SMFSC).

In addition to environmental management/operation approach to the river ecology, dam removal is another measure being critically reviewed as a potential stream restoration tool. After dam removal, restoration of unregulated flow regime would result in increased biotic diversity through the enhancement of preferred spawning grounds or other habitats. For coastal rivers, the interactions of cyclical freshwater flooding and marine tide would be re-built. Anadromous fish and shrimp often use spring floods to carry them to coastal breeding regions, while small, weak-swimming fish utilizes the tidal surge to move to upstream spawning ground (Bednaerk, 2001). By returning riverine conditions and sediment transport, the stream’s riffle and pool sequences as well as natural gravel or cobble bed condition would also reappear. It would restore the natural habitat and increase biotic diversity of the stream.

Regarding the three concerned urban streams of YLN, NTMN and YLBF, they are located at the upstream of the Mai Po Inner Deep Bay area in Hong Kong, which is designated as an internationally ecological important Ramsar Site (AFCD, 2013). The site and its upstream streams regularly holds 35 globally threatened species and near-threatened species, and supports on average 70,000 – 80,000 waterbirds in winter. They also hold over 1% of the global populations of *Platalea minor*, *Larus ridibundus* and *Tringa erythropus*. With the consideration of its ecological importance, the operating experience of the inflatable dams for YLBF, NTMN and YLN is reviewed to see if a balance between engineering function and ecological benefits can be achieved.

The inflatable dams at YLBF, NTMN and YLN have adopted different operation approaches to cater for a combined flood prevention, pollution control or agricultural need. YLBF is an engineered channel for flow diversion from upstream Yuen Long town centre. For the purpose of energy saving, the frequency of dammed water bypass pumping is reduced, and it cultivates a pond-like habitat upstream. The inflatable dam of NTML was incidentally damaged a few years ago but this broken dam re-establishes the connection between the stream and the bay, and the stream ecology is enhanced. YLN is a concrete channel running through the highly populated Yuen Long town centre, and the inflatable dam is found necessary for pollution control. However the community requested environmental improvement of the YLN and a rehabilitation scheme of part of the YLN was developed together with the public. Locations of the three concerned inflatable dams are shown in Figure 1.
2 METHOD

The review was conducted by retrieving the key operating parameters of the inflatable dam and interviewing the operators. The key operating parameters include power consumption, pumping hours and deflation frequency of the dams. For YLBF, we made use of the operation data from 2006 to 2012, since the dam commission in 2006. While for NTMN, we reviewed the operating data of the inflatable dam from 2005 to 2008, from its earliest available whole-year data available till its accidental damage in 2008. Operation data of YLBF inflatable dam in year 2004 was ignored because it was commissioned in end 2004, and the operation data covering only dry season was not representative.

To further review the ecological impacts brought by the pond-like habitat from YLBF and the removed dam at NTMN, we conducted an ecological survey at these two streams in February 2013. The survey findings would provide a snap shot of the stream ecology of the area.

3 YUEN LONG BYPASS FLOODWAY

YLBF is a drainage improvement project to divert part of the upstream runoff from Yuen Long town centre to alleviate flooding problems. The YLBF is a trapezoidal concrete channel of 30m to 50m wide and 3.8km long, extending from the Yuen Long main nullah in the south, to the Kam Tin River, and running to the Deep Bay estuary (TDD, 1998). The project was completed in 2006.

An inflatable dam was provided at downstream of the YLBF just prior to the connection with the Kam Tin River, to prevent saline, heavily polluted and sediment rich waters from the Kam Tin River backing into the YLBF and depositing residuals in the channel. Under the original design, the dam would be inflated under low flow conditions, and the dammed water would be pumped over the inflatable dam into the downstream Kam Tin River. When the pre-set water level of +2.0mPD (i.e. ~1.4m water depth whereas invert level of +0.63mPD) was reached, automatic pumping of the dammed water was initiated to prevent extended retention of polluted dry weather flow and associated odor and hygiene nuisance. However continuous pumping required large power requirement with annual electricity consumption of about 150,000kWh and resulted in 105tCO₂e emission (EMSD and EPD, 2010; HKU & CityU, 2010).

In order to respond to the rising concern of energy efficiency and carbon footprint, DSD commissioned a “pond” operation approach of the YLBF inflatable dam to reduce the pumping duration to achieve energy saving in 2008. Instead of using the automatic low flow pumping by
pre-set water level to regulate dammed water level, dammed water level would be controlled by gravity bypass system with flap valve at the outlet to prevent backflow, plus regular pumping once every 5 days, as shown in Figure 2. Pumping practice was changed from daily (2 – 4 times a day) in dry weather, to a 5-day pumping interval (with 4-hour pumping each time). The frequency of pumping was selected once in 5 days to avoid potential environmental nuisance brought by prolonged water retention. For instance, in case of storm events, the trapped floodwater could dilute the polluted dry weather flow and therefore deterioration of water quality would not happen within 5 days. The 5-day period is also shorter than the 7-day period required for a mosquito egg to grow to an adult mosquito. The revised “pond” operation approach significantly saved 70% power consumption, which is 100,000kWh per year and the corresponding carbon reduction is 70tCO₂e emission annually. It is observed from Table 1 that the percentage savings obtained from the entire pumping station are just slightly lower than that obtained from the total pump running hours. This suggests that the low flow pumps are the major source of electricity consumption of the inflatable dam (DSD, 2007).

This energy saving operation mode also cultivated a pond-like habitat upstream with wetland plant species found, and creating a pleasant looking environment to the community. However, research findings (Sharp 2012; Gerald, 1999) suggest that stream water depth higher than 1m would affect vegetation distribution then stays of migratory birds, and it was adopted as an effective means prohibiting the feeding of fish-eating migratory birds in fish ponds. Since the water depth of YLBF is maintained at about 0.67m to 1.8m (i.e. dam inflates at +1.3mPD and deflates at +2.5mPD, and invert level of stream of +0.63mPD), we then conducted an ecological survey to evaluate the ecological impacts brought by the “pond” operation approach of the YLBF, and details to be discussed below together with that for NTMN.

Figure 2 Inflatable dam with low flow pumping station for dammed water control under original operation scheme (left), and gravity bypass system for flow regulation under “pond” operation scheme (right)
Table 1  Operation performance of YLBF inflatable dam

<table>
<thead>
<tr>
<th>Year</th>
<th>Operation Mode</th>
<th>Electricity consumption (kWh/year)</th>
<th>Pump running hours (hour/year)</th>
<th>No. of dam deflation</th>
<th>Total Rainfall (mm)</th>
<th>Number of days with rainstorm signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Automatic low flow pumping</td>
<td>219,430</td>
<td>2,132</td>
<td>17</td>
<td>2,034.0</td>
<td>16</td>
</tr>
<tr>
<td>2007(1)</td>
<td>Annual Average</td>
<td>86,748</td>
<td>1,604</td>
<td>41</td>
<td>1,249.5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>68,090</td>
<td>533</td>
<td>31</td>
<td>2,783.0</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>76,340</td>
<td>851</td>
<td>13</td>
<td>1,441.0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>52,560</td>
<td>466</td>
<td>18</td>
<td>1,540.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>52,270</td>
<td>659</td>
<td>0</td>
<td>1,107.0</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>39,760</td>
<td>237</td>
<td>0</td>
<td>1,613.5</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Annual Average(3)</td>
<td>49,608</td>
<td>469</td>
<td>-</td>
<td>514.5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage Saving</td>
<td>68%</td>
<td>75%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes:
(1) Rainfall data were collected at the nearest Yuen Long rain gauge station.
(2) Several rainstorm signals (including amber, red and black rainstorm signals) hoisted in the same day is counted 1.
(3) Operation mode of YLBF was changed from automatic low flow pumping to “pond” operation mode in November 2007. For the ease of comparison, operation data for year 2007 were interpolated to 12-month data.

4 NGAU TAM MEI NULLAH

NTMN is an engineered channel connecting to Kam Tin River which discharges into Deep Bay. Similar to YLBF, there is an inflatable dam at the downstream of the nullah to act as a tidal barrier for pollution control. The dam also prevents the inflow of saline seawater which could potentially affect the use of the water for irrigation upstream. The operation mode of the inflatable dam at NTMN was similar to the original operation mode of YLBF, with automatic low flow pumping to avoid extended polluted dry weather flow retention at the dam upstream. Annual pumping hours of 2,900 hours and electricity consumption of 221,000kWh thus 155tCO₂-e emission were reported.

In view of the recent development on dam removal to enhance stream ecology worldwide, and the technical difficulties encountered in repairing the inflatable dam, it was decided to take this opportunity to evaluate if re-provision of the dam was needed. Since one of the main functions of the inflatable dam was to prevent the impact of salty tidal flow to upstream irrigation, consultation with local farmers, village representatives and other stakeholders on the need for the re-provision of a mini-dam at 2km upstream to suit the farming needs was conducted. However, the consultation results suggested that there were only 5 farmers left in the area and they planned to evacuate in the future. As such, a temporary mitigation measure with automatic pumping from NTMN during low tide (for about 6 – 7 hours a day) could provide good quality and adequate irrigation water for the farmlands. As the automatic pumping system was already installed since dam damage in 2008 with positive result, it was decided not to re-provide any dam structure in the NTMN (DSD, 2010a). In addition, further steps were taken to evaluate if any ecological enhancement or the potential of further energy saving could be brought by this “dam removal” incident of NTMN.

Notable ecological restoration of NTMN was reported. As advised by the green groups in the region, the undammed NTMN attracted a larger number of migratory birds to stay and the reconnection with the estuary created a healthy wetland habitat. Ecological survey was conducted at NTMN in February 2013 to collect some indicative information to evaluate the ecohydraulic improvement brought by the removed dam. The findings would be compared with that for YLBF, which is located in the same catchments of Deep Bay for reference.
### Table 2  Operation performance of NTMN inflatable dam

<table>
<thead>
<tr>
<th>Year</th>
<th>Operation Mode</th>
<th>Electricity consumption (kWh/year)</th>
<th>Pump running hours (hour/year)</th>
<th>No. of dam deflation</th>
<th>Total Rainfall (mm)</th>
<th>Number of days with rainstorm signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Automatic</td>
<td>281,605</td>
<td>3,606</td>
<td>-</td>
<td>2,021.0</td>
<td>14</td>
</tr>
<tr>
<td>2006</td>
<td>Low flow pumping</td>
<td>325,920</td>
<td>4,832</td>
<td>3</td>
<td>2,054.0</td>
<td>16</td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td>56,541</td>
<td>288</td>
<td>0</td>
<td>1,428.5</td>
<td>9</td>
</tr>
<tr>
<td>2008 (till June)</td>
<td></td>
<td>7,516</td>
<td>68</td>
<td>3</td>
<td>2579.5</td>
<td>9(4)</td>
</tr>
<tr>
<td></td>
<td><strong>Annual Average</strong></td>
<td><strong>221,355</strong></td>
<td><strong>2,908</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes:
1. Rainfall data were collected at the nearest Au Tou rain gauge station.
2. Several rainstorm signals (including amber, red and black rainstorm signals) hoisted in the same day is counted 1.
3. Annual average calculated based on January 2005 and December 2007. Since inflatable dam of NTMN was commissioned in late 2004, its operation data were not included to avoid confusion.
4. No. of rainstorm signals hoisted between January and June 2008.

### 5 ECOLOGICAL SURVEY FINDINGS OF YLBF AND NTMN

An ecological survey at YLBF and NTMN was conducted in February 2013 to evaluate the ecological performance of the two urban streams in the same Deep Bay estuary brought by the different operation approaches of the inflatable dams. Although the ecological survey was only able to provide a snap shot of these streams’ ecological performance, it provided indicative information of the ecological benefits brought by these stream management approaches. **Table 3** summarized the ecological survey findings.

The findings of the ecological survey indicated that both YLBF and NTMN provided a healthy habitat for different native wetland species. They also attract migratory birds to roost, including those bird species of conservation concern.

For comparison between two streams, NTMN accommodated a higher degree of biotic diversity with a larger number of birds and floral species surveyed, and also a larger number of bird counts in the survey. About 50% birds counted in the survey were wetland species. Also, the wetland plant species *Cyperus malaccensis* were commonly noted in the river bed covered with mudflat. These observations further suggest NTMN is a healthy wetland habitat. It is believed that the removal of the dam reconnects the stream with the Deep Bay estuary and restores the natural flow regime. Sediments are allowed to transport in NTMN and restores a muddy channel bed that provides a healthy habitat for the migratory birds to stay and wetland plants to grow. The surrounding area of NTMN also includes natural stream and pond and they further improve the habitat connectivity horizontally to attract birds to roost and feed in the channel. The removal of the dam in NTMN demonstrates a successful example to restore the ecohydrology of urban stream.

On the other hand, YLBF creates a pond like habitat upstream that returns a pleasant looking stream environment. Various plant species and bird species were recorded. However, it returns lower biota diversity than NTMN, especially the number of bird counts. This may be caused by the higher water depth maintained by the reduced low flow pumping frequency, but no strong evidence was obtained from the survey.

Based on the above observation, adoption of “pond” operation approach of the inflatable dam YLBF, or dam removal approach of NTMN both returned positive impacts to the stream ecology. It also achieved power saving and carbon emission reduction. No adverse upstream impacts, neither flooding cases nor environmental nuisance of dammed water or tidal backflow, were reported. It suggests that a balance between engineering performance and environmental enhancement can be achieved through these environmentally friendly dam operation modes. In addition, since no adverse environmental impact was reported from the undammed NTMN with tidal backflow from the Deep Bay area, it may be worthwhile to explore the feasibility to remove the inflatable dam at
YLBF or nearby streams to further enhance the stream ecohydrology as well as energy saving in the future.

Table 3 Ecological survey (dry season) findings of YLBF and NTMN

<table>
<thead>
<tr>
<th>River channel</th>
<th>YLBF</th>
<th>NTMN</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 plant species (most native, 13 wetland species)</td>
<td>20 plant species (most native, 16 wetland species)</td>
<td></td>
</tr>
<tr>
<td>Wedelia chinensis and Brachiaria mutica dominant</td>
<td>Panicum maximum commonly recorded</td>
<td></td>
</tr>
<tr>
<td>Panicum maximum</td>
<td>Bidens alba, Rhynchelytrum repens and Leucaena leucocephala commonly recorded on river embankment</td>
<td></td>
</tr>
<tr>
<td>Cyperus malaccensis (wetland species) commonly recorded from river bed covered with mudflat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38 species (most resident)</td>
<td>44 species (most resident)</td>
<td></td>
</tr>
<tr>
<td>183 (72 as wetland species) birds count in 3-day survey</td>
<td>191 (102 as wetland species) birds count in 2-day survey</td>
<td></td>
</tr>
<tr>
<td>14 species wetland dependent</td>
<td>18 species wetland dependent</td>
<td></td>
</tr>
<tr>
<td>10 species of conservation concern (Tringa ochropus as uncommon specie)</td>
<td>19 species of conservation concern (Anas platyrhynchos, Aythya fuligula, Corvus torquatus as uncommon species, Larus cachinnans as scare winter visitor)</td>
<td></td>
</tr>
</tbody>
</table>

Survey results of herpetofauna, freshwater fish and aquatic invertebrates returned similar findings for YLBF and NTMN, and no rare species were recorded. Data are thus not shown for clarity.

6 YUEN LONG NULLAH

YLN is an urban stream of about 12km long with sizes ranging from 7m to 70m wide and 3 to 4m deep, traversing through the urbanized Yuen Long town centre. Similar to YLBF and NTMN, an inflatable dam was constructed at its downstream prior to Shan Pun River in 1992 as a tidal barrier for pollution control. In view of the poor water quality of the upstream flows, including expedient connections and polluted runoff from farms, and the highly populated riverbanks, retention of dammed water by adopting “pond” operation approach as YLBF would cause unpleasant visual impacts and environmental nuisance. It would also attract a lot of complaints from the residents (DSD, 2007). Therefore, the inflatable dam should be maintained with continuous low pumping to avoid water retention during low flow condition, and deflate in storm events for flood control.

In addition, the local residents increasingly requested DSD to rehabilitate YLNF with a better environment and reduce the nuisance caused by the polluted baseflow (Chan, 2010; DSD, 2009). In order to identify the community aspirations, we conducted a comprehensive public consultation exercise to collect and consolidate the public views to formulate the nullah rehabilitation. We also took this opportunity to educate the community on the functions and correct use of the nullah. A series of consultation activities, including meetings with local community groups, workshops and follow-up meetings with green advocacy groups and local universities, and drawing competitions, were held between May 2007 and December 2008.

In the consultation, it was understood that the public had four major areas of concern, including water quality, flood protection, enhancement of public amenities and recreational areas, and improvement of aesthetics for the stream rehabilitation project. Some suggestions such as decking, widening and deepening the channel, and naturalizing and greening the nullah were noted. With the considerations of different technical, societal, monetary considerations and environmental enhancement, the first rehabilitation phase was designed to rehabilitate the town centre section. Polluted dry weather flow from expedient connection would be intercepted upstream and diverted to the Yuen Long Sewage Treatment Works for treatment. Treated effluent would be re-circulated back to the upstream section to discharge in order to maintain a minimum baseflow at the YLN to dilute the polluted urban runoff. It could improve the water quality and resolve the odor concerns of the nullah running through the town centre. The channel bed would also be reconstructed with
natural landscaping, pebble stones bed, small cascades, etc. to cultivate a “natural” environment for aquatic life. The rehabilitation scheme of YLN is shown in Figure 3. This rehabilitation scheme is found echoed with Singaporean ABC Waters Programme and Seoul’s Cheong Gye Cheon project to rehabilitate those urban streams running through the urban area thereby to enhance the living environment, and also to increase the biotic diversity of the streams.

**Figure 3 Photomontage of YLN rehabilitation scheme**

7 CONCLUSION

This paper reviews the operation experience of the three inflatable dams in the urban streams in the ecological sensitive Deep Bay estuary, including YLBF, NTMN and YLN. For YLBF and NTMN with relative good upstream water quality, operation of inflatable dams for flood prevention and pollution control should take into account of environmentally friendly approach. For example, YLBF adopts a “pond” operation approach of the inflatable dam. The use of gravity bypass system and extended low flow pumping for dammed water effectively saves about 70% power consumption, i.e. 100,000kWh then 70tCO₂e emission annually. Dam “removal” in NTMN successfully restored the connectivity between the stream and the estuary, and cultivated a wetland habitat for the migratory birds to feed and roost. No unpleasant environmental nuisance e.g. odor caused by tidal backflow was reported. These environmentally friendly operation approaches do not only enhance the ecological values of the streams, but also significantly save the annual electricity consumption for low flow pumping.

However for YLN with polluted upstream discharge, inflatable dam with continuous low flow pumping is considered important to avoid accumulation of polluted runoff in the stream. The upstream channel has to be maintained dry to prevent odor and environmental nuisances induced by polluted dammed water. However, public aspirations of stream rehabilitation for a better living environment were heard. After a series of consultation activities, a rehabilitation scheme of YLN town centre section was developed, taking into account its engineering function for flood control, environmental enhancement for improved water quality and elimination of odor nuisance, and social considerations on the provision of public amenities and aesthetic enhancement of the YLN traversing their town centre. The experience of YLN rehabilitation scheme demonstrated a successful public engagement exercise in developing a balanced solution among engineering functions, environmental considerations and public expectations. Experience obtained in YLN rehabilitation should be
referred in future mass infrastructural project.

Based on the three operation approach of the inflatable dams in YLBF, NTMN and YLN under the same Deep Bay estuary, it is noted that stormwater management for urban stream is site specific. A balance has to be strived to develop the most appropriate management approach with due considerations on stream water quality and flow, engineering functions, environmental considerations, community aspirations, and economic impacts. It is also observed that stream management practice has to be reviewed from time to time. For example, a paradigm shift in stormwater management solely from its flood control capability to the importance of ecohydraulics and carbon footprints have been observed in the operation approaches adopted in YLBF and NTMN. Also, stakeholder engagement plays an important role in urban stream management nowadays.

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