Upper Catchment Stormwater Diversion with Drainage Tunnels

John K Y Leung
BSc(Eng) Hons MSc(CPM) MEngSc MHKIE MIEAust
Drainage Services Department

M H Leung
BSc(Eng) Hons LLB Hons MPA MHKIE
Drainage Services Department

The Drainage Services Department is investigating a new approach to mitigate flooding in the older urban areas by using tunnels to divert the stormwater runoff coming from upstream.

Hong Kong is a hilly area; most catchments have steep undeveloped upstream areas which drain to the flat downstream urban areas. In order to improve the downstream drainage conditions, the stormwater runoff from upper catchments can be intercepted at a high level and conveyed to suitable discharge locations through large diameter drainage tunnels. Since less runoff is discharging through the downstream drainage network, a higher flood protection level can be achieved with the existing systems. The flood risk at the urban areas is reduced and so is the necessity for any drainage improvement constructions.

Presented in this paper is a brief account of the drainage problems in the urban areas of Hong Kong; the common drainage improvement methods; and the development of the upper catchment diversion tunnel approach and its applications.

Keywords: *Flood Conveyance, Flood Storage, Flood Diversion, Upper Catchment Diversion, Stormwater Drainage Tunnel*

INTRODUCTION

With rapid development in Hong Kong for the past decades, the drainage systems in some older urban areas are found to be unable to meet the contemporary design standards. These urban areas are usually situated at the catchment downstream and the land has already been developed. Improvement of the drainage network will unavoidably cause severe disruption to the public. The Drainage Services Department is considering an upper catchment stormwater diversion approach, under which stormwater from the upper catchment is intercepted and conveyed through large diameter tunnels to suitable discharge locations. The extent of excavation associated with traditional drainage upgrading construction can then be reduced.

DRAINAGE PROBLEMS IN THE OLDER URBAN AREAS OF HONG KONG

Most urban areas in Hong Kong fall within a strip of reclaimed land along the coast. Catchments containing urban areas share the common characteristics of having a steep and undeveloped upstream with a flat and highly urbanised downstream. The upper catchment has steeper gradient and is less vulnerable to flooding because the stormwater runoff can flow quickly to the downstream by natural over-land flow or through man-made drainage conduits.

Meanwhile, the downstream urban areas are facing an increasing need to improve the drainage conditions. Part of the reason is that the contemporary flood protection standard is higher. In the old design standards [4], a fixed tide level of 2.5 mPD is used as the outfall boundary condition for hydraulic analysis. But in the Stormwater Drainage Manual [5] issued in 1994, the protection against flood under tidal influence has been upgraded. The concept of "combined flood effect" under different combinations of extreme tides and design rainstorms was introduced. Since drainage systems in the downstream urban areas are more susceptible to tidal influence, the design extreme sea level criterion is often the controlling factor. To achieve the higher standards, some existing drainage systems may have to be improved.

Further reclamation beyond the existing shoreline may also increase the need for upgrading the hinterland stormwater drainage systems. Under the fast economic development of Hong Kong, land is reclaimed and the shoreline is extended to the sea. These reclamation works lengthen the drainage path, resulting in a reduction in hydraulic gradient and an increase in friction head loss to the flood flow. The drainage capacity of the existing system will be reduced. In order to provide the required drainage capacity, improvement works at the reclamation hinterland are required.

Another problem associated with reclamation comes from the higher site formation level of the new reclamation. Before reclamation, part of the stormwater runoff under extreme condition can be discharged to the sea by flowing over the seawall. After reclamation, the higher formation will block this over-land flow and create a local low spot around the original sea frontage.

Urbanisation of the upstream areas can also increase the peak flow. While the downstream shoreline is being pushed towards the sea, intensive development is taking place at the upper part of the catchment. The originally vegetated areas are paved up by roads and buildings. More runoff is generated and the flood flow can reach the downstream faster through the man-made conduits.

COMMON FLOOD MITIGATION APPROACHES

Common flood mitigation measures include structural and non-structural means. The former refers to those requiring construction works, while the latter includes legislative or management measures. The most effective measure for a particular catchment can be a combination of the two. In any case, the geographical and socio-economical characteristics of the catchment should be considered thoroughly during the formulation of the overall flood mitigation strategy. These characteristics include topographic features, land use, ecology, social and economic conditions, and all activities influencing the hydrologic responses of the catchment. The involvement of the local people is essential such that they can contribute their views and preferences to the strategy. In the broad terms, flood mitigation is only a component in the comprehensive management of a drainage catchment. One systematic approach on managing a catchment, called the Total Catchment Management, is discussed in [8].

In this paper, the discussion is confined to structural measures only. Common structural approaches on flood mitigation include Conveyance, Storage, Infiltration, and Cross-catchment Diversion. The choice of any measure will unavoidably induce impact to the equilibrium of the catchment. In planning flood improvement works, it is pertinent to consider the overall effect of the proposed measure to the catchment as a whole.

A) Conveyance by Drainage Works

Channels or pipelines are the conventional means to convey stormwater to the discharge locations. However, drainage structures are buried in the ground and often massive in size. Once laid in position, they are not flexible to respond to hydrologic changes taken place in the catchment, e.g. the increase in flood flow due to further development upstream.

B) Flood Storage

Storage is applicable when the downstream drainage capacity is insufficient to meet the increased runoff arising from upstream developments. It is based on the principle of storing a portion of the surface runoff coming from the upstream such that the flow rate is restricted to stay within the capacity of the downstream drainage systems. The concept and some case studies are discussed in more details in [9].

C) Infiltration and Groundwater Storage

Increased infiltration is useful in areas where the soil is permeable, e.g. sand or silt. It is based on the principle of reducing the stormwater runoff by enhancing the absorption of rain into the ground. Infiltration facilities include porous pavement, grass surface, infiltration ponds, soak-away pits, and groundwater charging points. [12]

D) Cross-Catchment Diversion

Cross-catchment diversion involves diverting the stormwater runoff from a catchment to another. It can significantly change the catchment hydrology and is often carried out for the supply of potable water, irrigation, hydropower generation, or navigation.

DIFFICULTIES ASSOCIATED WITH COMMON APPROACHES

In Hong Kong, most urban areas are reclaimed from the sea. The major traffic routes are running parallel to the shoreline, e.g. on Hong Kong Island the Des Voeux Road, Gloucester Road, Hennessy Road, and Connaught Road. The trunk drains, which run from the hillside towards the sea, are in turn cutting through all these main traffic routes. Upgrading of the trunk drains would lead to excavating the major roads, blocking the traffic, and causing serious disruption and great inconvenience and nuisance to the public.

Finding space to install the drainage pipeline amongst the congested underground utilities is also a problem. Drainage culverts are very large in size at the downstream. The flat gradient of the ground limits the flow velocity and large culverts are required to convey the flow. It is not uncommon to find 3-4 cell box culverts measuring over 10 m wide under the roads. Drainage improvement by laying more conduits is therefore only applicable when the size is small or the site is located away from the major traffic routes.

Flood storage facilities usually consume large land areas and are difficult to implement in the urban areas of Hong Kong. Tunnel approach is a promising form of underground storage and is successfully applied in Japan [6]. It requires minimal ground surface area and causes less disturbance to the public during construction. If the tunnel is deep enough, it can also overcome restraints induced by the foundations of the buildings. However, additional pumping effort will be required to raise the stored water to ground level for discharge.

Infiltration approach is not desirable to the upper catchments of Hong Kong as excessive infiltrated water may affect the stability of slopes. Furthermore, the movement of water under the ground surface is slow. During extreme rainstorms, most of the runoff will flow to the downstream by over-land flow instead of infiltrating into the soil.

Diversion approach is a possible solution in relieving the pressure on drainage systems at the downstream urban areas. In Hong Kong, the upper catchments are generally undeveloped and impose less constraint to construction works. It is feasible to intercept the stormwater runoff from the upper catchment and divert it away to suitable discharge locations, such as the sea or river channel with spare capacity.

The usual forms of diversion structures are open channels or viaducts. The planned Yuen Long Bypass Floodway is an example of channel diversion but is not suitable for the upper catchments of Hong Kong. The large channel at the mid levels is unsightly and will wipe off large area of green and relatively natural landscape. Cutting a deep channel will also aggravate the slope problems at the already steep topography. Viaducts are commonly used for irrigation or water supply purposes. They are designed to meet regular flows. If they are built to meet extreme rainstorm events, they will be very large in size and become costly.

UPPER CATCHMENT DIVERSION WITH DRAINAGE TUNNELS

The upper catchment diversion approach with drainage tunnels is evolved from a combination of different drainage improvement methods. Its schematic layout is shown in Figure 1. Stormwater runoff from the upper catchment is intercepted with vortex intakes, through vertical shafts to the underground tunnel, and then discharged to suitable locations.

Through diverting part of the stormwater generated from the hillside, the peak discharge passing through the downstream drainage network can be reduced. Loading to the trunk drain at the urban area is reduced and the necessity for improvement is eliminated. Another advantage is that by lowering the water level in the trunk drain, stormwater in the branches can flow more easily into the trunk. The overall performance of the downstream drainage network will be enhanced.

Since experience in hard rock tunnelling is available in Hong Kong, deep tunnel is considered appropriate for the diversion schemes. Unsightly open cuts, land surface disruption and vegetation removal for channel construction will be minimised. Furthermore, the tunnel is located deep inside the sound rock formation and will not affect the stability of slopes along the hillside. When sufficient rock cover above the tunnel can be

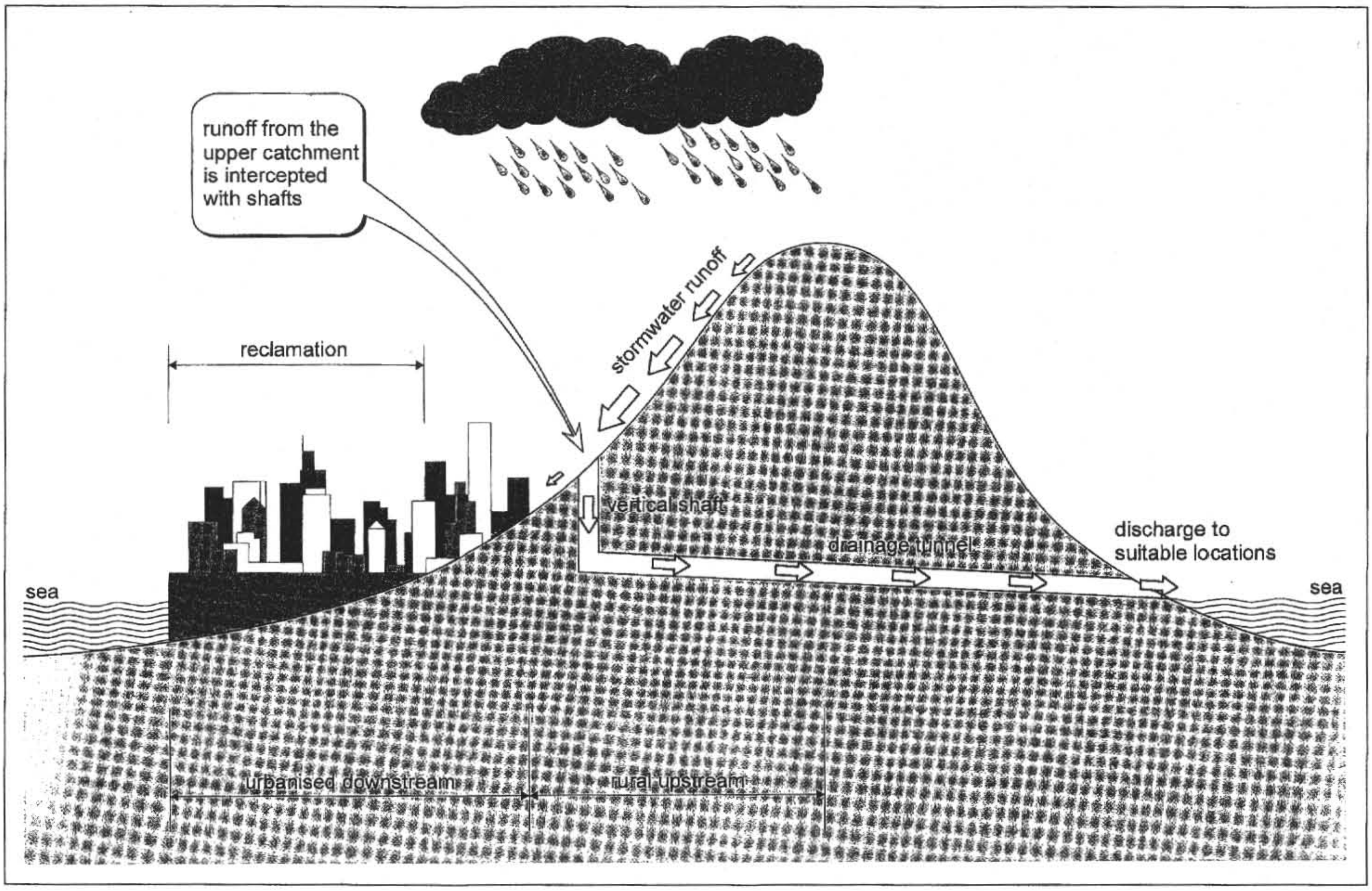

Figure 1 – Schematic Layout of Drainage Tunnel Approach

provided, foundation of the existing buildings will impose less constraint on the tunnel alignment. Nevertheless, easements and proper legislation must be arranged such that the tunnel may pass through private lots if necessary.

The tunnel can be lined to reduce ingress of ground water, and also minimise the impact to the water table and vegetation cover of the rural upper catchments. Since the collected stormwater inside the tunnel is under high hydraulic head at the great depth, the tunnel lining can also reduce leakage of water to the underground.

Drainage tunnels have also been built in Japan and Australia recently [1] [3] [7]. However, they differ from the above mentioned approach in that their outfalls are below ground level and pumping is required to remove water from the tunnels. Meanwhile, the steep topography of Hong Kong enables the whole tunnel alignment to stay above sea level and conveyance of the water flow is purely by gravity. As pumping is not required, the operation and maintenance cost can be significantly reduced. By providing an adequate gradient to the invert level, the flood flow becomes self-cleansing and silt deposition in the tunnel is minimised.

To further reduce the maintenance effort, any contaminated low flow or first flush is designed to bypass the interceptor and will not be collected into the tunnel system. Only the excessive stormwater runoff will overflow into the interception point and be diverted away. Since the tunnel is free draining, a dry working condition can be provided and the tunnel invert can be assessable by mechanical plant. Routine inspection and maintenance is possible, despite the usual practice for working within confined space should always be followed.

The construction cost of a drainage tunnel is in general higher than the conventional pipe-laying constructions. Furthermore, deep tunnelling is a very specialised and difficult construction project, thorough investigation and planning is essential. Detailed assessment on cost-effectiveness of the different options should be considered for the choice of an optimum drainage improvement scheme.

APPLICATIONS OF THE APPROACH

The upper catchment diversion approach with drainage tunnels is being considered by the consultants for some drainage improvement studies undertaken by the Drainage Services Department, namely:

- West Kowloon Drainage Improvement Study - Stage 2 [2]
- Stormwater Drainage Master Plan Study in Northern Hong Kong Island [10]
- Stormwater Drainage Master Plan Study in Tsuen Wan, Kwai Chung & Tsing Yi [11]

Stormwater tunnels are proposed in these studies for flood mitigation. The tunnel schemes are at feasibility study stage and some information is listed below. The preliminary tunnel alignments are shown in Figure 2.

Catchment Area	Estimated Cost (HK$M)	Discharge Location	Length (km)	Size (m dia)
West Kowloon	520	Kai Tak Nullah	2	4
Northern Hong Kong Island	1,700	Kong Sin Wan	10	5.5-8
Tsuen Wan	1,100	Yau Kom Tau	6	6.5

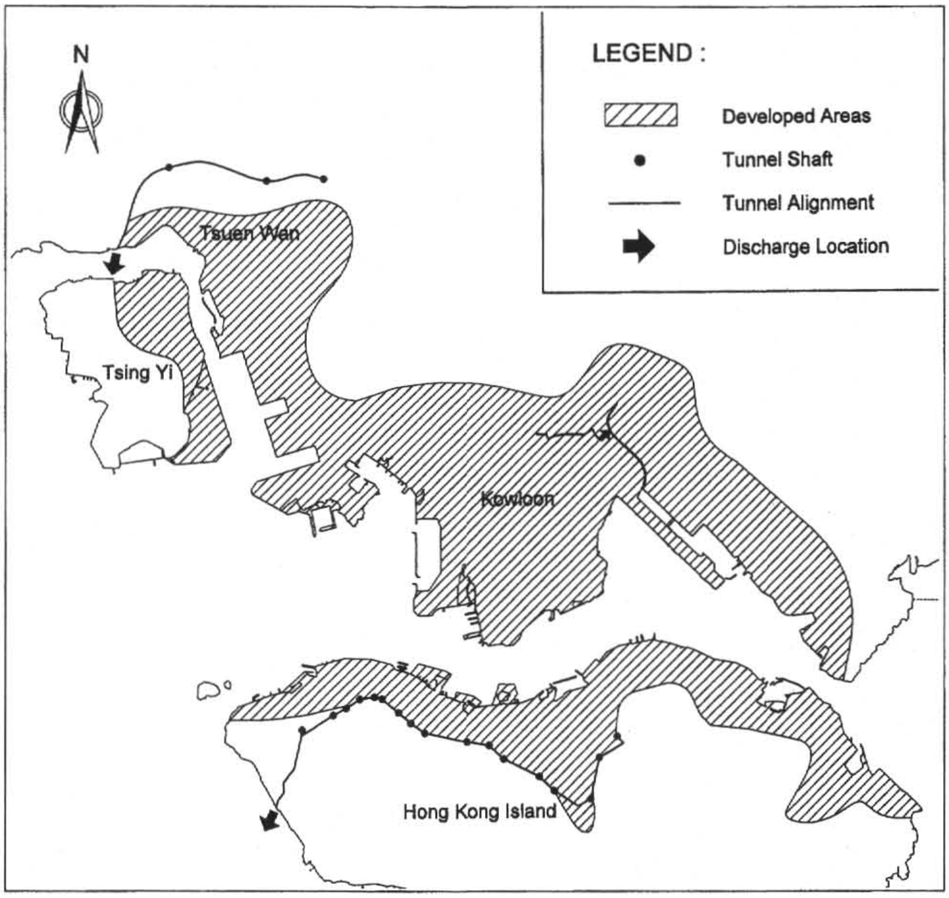

Figure 2 – Preliminary Alignments of the Proposed Drainage Tunnels

CONCLUSION

The underground space in an urban area is filled with different kinds of utilities, eg power cables, communication cables, water mains, cooling water pipelines, drainage and sewerage pipelines, vehicular underpasses and pedestrian subways, Mass Transit Railway, etc. They are all competing for space within an extremely congested environment. In fact, underground space in an urban area is a limited resource and its share in use should be allocated under careful planning.

For new site formations, the allocation of underground space can be made possible through reservation of land use, e.g. drainage reserve, Mass Transit Railway reserve, etc. But for the older urban areas, the underground space is already occupied and it would be very difficult to install additional utilities. The condition is particularly stringent when the utility occupies large space or its vertical alignment is strictly restrained, eg drainage pipelines.

An alternative approach on drainage improvement works is required under such circumstances. The adoption of an upper catchment drainage diversion approach with the use of deep tunnels has two major advantages. Firstly, by intercepting runoff from the upper catchment, the extent of downstream drainage improvement works can be reduced. Secondly, with the use of deep tunnel construction method, the disruption to the existing utilities and traffic will be minimised.

The upper catchment drainage diversion approach is applicable to topographies with high and steep upper catchments, such that the intercepted stormwater can be conveyed by gravity to the desirable discharge locations. It is not applicable to low-lying and flat catchments such as Indus or Kam Tin. Furthermore, because of the high construction cost, it is financially viable for relieving flooding problem in the developed urban areas only. This paper presents the general concept of the approach, but details of the application should be designed to suit the individual project conditions.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Director of Drainage Services for permission to publish this paper. However, the views expressed are those of the authors and do not necessarily reflect in any way the official views or policy of the Government of Hong Kong SAR.

The authors also wish to thank the support from their colleagues in the preparation work. They are particularly in debt to Prof Y K Tung of the Hong Kong University of Science and Technology, Prof James Ball and Dr K C Luk of the University of New South Wales, and their dear friend Mr Andrew Hee, for their technical advice on the paper and sharing with the authors their knowledge and experience on flood management.

REFERENCES

[1] Asche, H.R., Preliminary Design for High Speed Tunnelling on the Northside Storage Tunnel Project, *International Conference on Urban Ground Engineering, Hong Kong* (Nov 1998).

[2] Binnie Black & Veatch Hong Kong Ltd., *West Kowloon Drainage Improvement - Stage 2, Working Papers No. 1 (Dec 1997) and No. 2* (Jul 1998).

[3] Cargill, R., Construction begins on Water Storage Tunnel under Northern Sydney Suburbs, *Civil Engineers Australia* (Sep 1998).

[4] Civil Engineering Services Department, *Civil Engineering Manual Volume VI - Sewerage and Drainage* (1978).

[5] Drainage Services Department, *Stormwater Drainage Manual* (1994).

[6] Fujita, S., Stormwater Management in Congested Urban Areas in Tokyo, *International Symposium on Urban Stormwater Management, Sydney* (1992).

[7] Kazuyuki Higuchi et. al., Sewer System for Improving Flood Control in Tokyo : a Step towards a Return Period of 70 Years, *Water Science Tech.*, Vol. 29, No. 1-2 (1994).

[8] Leung, J.K.Y., *Total Catchment Management and its Application in Hong Kong*, MEngSc Project, School of Civil Engineering, University of New South Wales (Mar 1996).

[9] Leung, J.K.Y. and Leung, M.H., Flood Storage and Some Case Studies, *HKIE Group 1 Proceedings*, Vol. 2 No. 1 (Nov 1999).

[10] Maunsell Consultants Asia Ltd., Stormwater Drainage Master Plan Study in Northern Hong Kong Island, Working Paper No. 12 - *Strategy Development* (Nov 1998).

[11] Montgomery Watson, Stormwater Drainage Master Plan Study in Tsuen Wan, Kwai Chung & Tsing Yi, Working Paper No. 5 - *Review of DMP Strategies* (Jul 1997).

[12] Urbonas, B. and Stahre, P., Stormwater, *Best Management Practices and Detention for Water Quality, Drainage, and CSO Management*, Prentice Hall Inc. (1993).

ISSN 1680-5259

香港工程師學會

THE HONG KONG INSTITUTION OF ENGINEERS

PROCEEDINGS

VOLUME 3 NUMBER 1

JULY 2001