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"STORMWATER MANAGEMENT AND ROAD TUNNEL (SMART) An Underground Approach to Mitigating Flash Floods"

by

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SYNOPSIS

Kuala Lumpur (KL) the Capital of Malaysia was founded in the late 19th century as a tin mining settlement at the muddy confluence of two rivers; the Klang and the Gombak. A century later it has become the nation's largest city and the heart of commerce and business. The transformation of KL into the ultra modern metropolis as it is today has not been without its trials and challenges, and the rapid development of the last three decades has brought with it urban congestion, traffic gridlock and devastating bouts of flash flooding.

KL is situated in the mid upper reaches of the 120 kilometer long Klang River which drains a catchment of some 1,288 sq. km. The river originates in the state of Selangor, flows through the Federal Territory of KL before re-entering Selangor where it meanders through gently rolling lands and a flat coastal plain and finally discharges into the Straits of Malacca. Situated in a flood plain, KL has experienced a number of major flood events with the worst recorded being the flood of 1926. However, it was only after the disastrous flood of 1971 that efforts were initiated to resolve the flood problem.

By the mid 1970's, a flood mitigation Master Plan had been developed for the Klang River Basin which incorporated a number of engineering options including upstream storage, poldering and pumped drainage, and improving the capacity of the Klang River and its major tributaries. During the 1990's the pace of development increased with more green areas being urbanized and this resulted in a three-fold increase in the annual discharge of the Klang River at the city center. Entering the millennium, flooding of the city has become an annual event.

This paper will look at the KL flooding problem and its causes, and trace the engineering efforts to contain it, utilizing both structural and non-structural measures and culminating in the present works under the Stormwater Management and Road Tunnel (SMART), a unique and innovative dual purpose tunnel to handle both flood and traffic flow.

1.0 INTRODUCTION

The city of Kuala Lumpur (KL), the Capital of Malaysia, is located at the confluence of the Klang and the Gombak rivers in the Klang river basin. The Klang river basin encompasses an area of about 1,288 km^2 of which 244 km^2 lies in the Federal Territory of Kuala Lumpur and the balance in the state of Selangor.

Over the years KL has grown from a small mining town to become Malaysia's largest city, and it has been the center of the country's economic development over the past half century. It is estimated that about 50 percent of the Klang River Basin has been developed for residential, commercial, and industrial use, making it the most densely developed region in Malaysia with a population of about 3.7 million people, of which 1.3 million reside in the city. As a result of the rapid pace of development, occurrences of flash floods have become common, due to the change in hydrological characteristics combined with a silted and clogged drainage system.

The transformation of KL into the ultra modern metropolis it is today has not been without trials and challenges to the Government. As development kept changing the face of the city, existing infrastructures came regularly under pressures to service demands beyond their design limits. Meanwhile, the urbanization of the catchments in and around the city has resulted in flood runoffs which are many-fold the capacity of the river system, bringing with it challenges for the engineers to come up with innovative engineering solutions.

2.0 TOPOGRAPHY

Much of the surrounding areas of Kuala Lumpur are built on hills some of which have near vertical slopes and rising to 1430 meters; whilst within the city the land rises gradually away from the river. The river's headwaters comprise mountainous and steep terrain covered almost entirely by a thick canopy of tropical jungle. The mid upper reach where KL is situated is generally less steep and lies between 30 and 60 meters above mean sea level. The area has mostly been built-up into township, residential estates and industrial parks. It is by far the most heavily populated part of the basin. About 8 km downstream of the city, the terrain flattens somewhat and the Klang Valley rapidly widens to 24 km or more with a maximum elevation of 15 – 20 meters above sea level.

The river downstream of KL flows through gently rolling lands and a flat coastal plain before discharging into the sea. The rolling grounds have mostly been converted to agriculture lands for estate type planting of commercial crops such as rubber and oil palm. The flat grounds fronting the coast, which are generally below high tide levels, have been diked at many locations and provided with improved drainage to enable the cultivation of crops such as rubber, oil palm and coffee. In recent times however, a sizeable portion of these estate lands have been converted for development into new townships and residential areas. This process of land use conversion is expected to be a feature for some time in the foreseeable future.

For all intent and purposes therefore, the Klang River catchment is in a dynamic state of constant change through development activities that would keep altering its hydrological and geomorphologic feature for some time yet to come. The Klang River is 120 km long starting from the hills and ending in the sea. The principal tributaries of the Klang River System, namely the Batu, the Gombak and the Ampang rivers join the main river just upstream of the city. Of its two bigger tributaries, the Gombak River is about 27 km long and drains an area of about 122 km^2 and the Batu River is 24 km long with a drainage area of 145 km^2. The annual mean rainfall in the basin ranges from 1,900 mm near the coast to 2,600 mm at the foothills.

3.0 FLOODING OCCURRENCES

Topographically, Kuala Lumpur was built along the flood plains of the Klang River and thus, from the earliest days, has been subjected to flooding. Because of the intensity of development and its impact on the ground, flood magnitudes keep on mounting year by year leaving far behind the capability of the city's drainage system to cope with it. The earliest recorded flood incident was the flood of 1926. The largest in recent history was the flood in 1971. This particular event was widespread and affected a number of other States in the country as well. The 1971 flood lasted for 5 days and resulted in extensive damage to property, infrastructure, agriculture land and crops. About 445 hectares of land in the city were inundated to various depths of up to 2 metres and the damage suffered was estimated to be in the region of RM 36 (US$ 10) million.

Over the past decade, incidences of major flooding have become more frequent (see Table 1). In addition the city has been affected by occurrences of flash floods which descend with hardly any warning and totally upset city routine.

Table 1 Flooding Incidences in KL

Period	No of times	Year
Before 1950	1	1926
1970s	1	1971
1980s	3	1982,1986, 1988
1990s	4	1993, 1995, 1996, 1997
2000 to date	5	2000, 2001 (Apr & Oct), 2002, 2003

4.0 CAUSES OF FLOODING

The rapid pace of development in the upper catchment area has been singled out as one of the main causes of flooding. Land use conversion from rural to urban use has been rapid over the past two decades. Large areas of land have been converted from forest to paved surfaces, thus significantly raising runoff. Forest lands are capable of absorbing 100 mm of rainfall in the first hour of a storm but can only absorb 20 mm of rainfall under urban conditions.

Major floods occur due to moderate intensity long duration rainfall over a large part of the upper catchment, resulting in rivers over-flowing their banks while flash floods are due to high intensity short duration rainfall and short runoff time of concentration over-loading the capacity of the local drainage systems. Typically, storms with 3 hour rainfall of 86 mm occur on a 2 years return period, while for return periods of 50 years and 100 years respectively, rainfall of 130 mm and 142 mm can be expected.

At the same time, the capacity of the river system has been reduced due to heavy siltation. The large volume of sediment (Tables 2, 3 and 4) that currently enters the drainage systems is the result of poorly controlled land clearing activities. In addition to this, off-river flood storage has been significantly reduced due to development in the flood plain and the filling up of old mining ponds.

Table 2 Sediment Estimates (1989)

Suspended Sediment load	Quantity (tonnes/yr)	Catchment Area (km^2)
Batu River at Sentul	183,000	145
Gombak River at Tun Razak Bridge	200,000	122
Klang River at Yap Kwan Seng	67,000	160
Klang River at Sulaiman Bridge	306,000	468

Table 3 Sediment Estimates (1994)

Estimate of Sediment Inflow into	Quantity (m^3/ annum)
Batu River	200,000
Gombak River	200,000
Klang River	110,000
Klang River at Sulaiman Bridge	180,000
Puchong Drop (from Sg. Klang & Tributaries)	340,000

Table 4 Comparison of Sediment Yield

Country	River	Basin Area (km^2)	Sediment Yield ($t/km^2/yr$)
Malaysia	Jinjang @ Bulatan Kuching	27.1	2,283
	Klang @ Jln Yap Kwan Seng	83.0	807
Thailand	Nam Yuan	4890	2,045
	Lam Dom Noi	2060	3,874
Indonesia	Cilutung	600	12,000
	Wuryantoro	33.2	1,031
India	Ganges	955,000	1,500
	Brahmaputra	660,000	1,100

There are also constrictions to the river flow especially from the piers of the numerous bridges spanning the river. Amongst these, the constriction due to the Tun Perak Bridge together with the adjoining STAR LRT platforms is considered the worst. Other notable constrictions include piers of the LRT line along the banks of the Klang River and the piers of the elevated highway piers near Jalan Sultan Ismail. All these factors contribute in one way or other to retarding the flow in the river channel and thus increasing the floods in the city center.

5.0 FLOOD MITIGATION WORKS

The early flood mitigation works in Malaysia were carried out by the Hydraulic Branch of the Public Works Department. In 1932 the Department of Irrigation and Drainage (DID) was formed and it took over this function. Some of the early works are :

- **i)** Straightening of the Klang River in 1915
- **ii)** Rechannelisation and protective works of the Klang River, completed in 1933
- **iii)** Construction works by the Klang River Dredging and Petaling Tin companies completed in1937 and 1941
- **iv)** Improvement of the Klang River through the city, completed in 1960
- **v)** Improvement of the Gombak River, completed in 1969.

5.1 Kuala Lumpur Flood Mitigation Project

The big flood of 1971 prompted the DID to establish the Kuala Lumpur Flood Mitigation Project. The main project features consists of 3 dams located on the Klang, Gombak and Batu Rivers and urban drainage works on the tributaries of these three main streams. The following measures were recommended :

- **i)** **Channel Improvement** :- The river Channel improvement involved the widening, deepening and straightening about 47.2 km of river channel above the Puchong Drop and the removable of the Puchong Drop Structure. Within the city where space is restricted, sections will be deepened and lined. A major portion of this works have been completed while some improvement works on the Klang river is ongoing.

- **ii)** **Klang Gates Dam Modification** :- The height of the gravity arch concrete dam completed in 1959 has been raised by 3 meters to an elevation of 97.8 meters in 1980. The new active capacity of 28.8 million m^3 is an increase of more than 76 percent over the 16.3 million m^3 previously. An additional land area of 71 ha of forest reserve was required. New spillway piers, gate hoists and 4 radial gates were installed in the spillway. All the works were completed in 1981.

- **iii)** **Batu Dam and Reservoir** :- The construction of this dam at the confluence of the Batu and Tua Rivers would control surface runoff from a catchment of 50.2 km^2. This earthfill embankment dam, impounding water to an elevation of 103.8 m created a reservoir capacity of 36.6 million m^3 and a total area of 250 ha inundated at elevation 107.3 metres. This is a multi-purpose flood control and water supply dam. Construction was completed in 1987 at a cost of RM 20 million (excluding land acquisition). The outlet can discharge 58 m^3/s and together with the spillway (capacity of 195 m^3/s), giving a total discharge capacity of 253 m^3/s at maximum water surface of El.107.3 m. The reservoir provides an additional 1.34 m^3/s (25 mgd) of domestic and industrial water supply to the Klang Valley.

iv) **Gombak Dam and Reservoir** :-This was a proposed multiple-arch concrete structure of 25 meters height and a reservoir capacity of 42.6 million m^3 covering an area of 82.3 ha. However, an additional 411 ha of land is needed for roads, services and other project functions. The Gombak Dam project was shelved due to social opposition from the 1,110 families comprising of 4,523 people residing in the reservoir area.

v) **Batu Retention Pond** :- The Batu Retention Pond was proposed as a partial replacement for the Gombak Dam. The Batu Pond has since been completed in 1993 and the Gombak River Diversion (3.4 km) completed in 2003. The Pond is designed to carry a flood discharge (100 years return period) of 60 m^3/s from the Gombak River via a diversion channel, and 40 m^3/s from the Batu River.

vi) **Pumphouse :-** Kampung Baru is an area of about 90 ha is located on the right bank of the Klang River about 2 km upstream of the Klang/Gombak confluence. About 35 ha of this area is below the designed level of the Klang River and of this, 15 ha suffers from flooding due to internal water inundation as the area is relatively low. To mitigate the flooding, a pumphouse and a storage basin was constructed alongside the embankment of the river in 1993 at a cost of RM 2.6 million. 3 Nos. of 110 kw submersible pumps with a capacity of 1 m^3/s each were installed.

5.2 Flood Bypass

Work on the Kuala Lumpur Flood Mitigation Project commenced in the mid 1970s but the pace of implementation was limited by the availability of funding. In the meantime, the rate of development of KL and the surrounding environs picked up at a much higher level and consequently flood discharges began to outpace the improvement to the river capacity through the flood mitigation works.

At the city centre, the Klang River system drains a catchment totaling 465 km^2; of which approximately three quarters is unregulated. Seventy percent of these free draining lands has been intensely developed and this has cause the runoff response to rainfall to be quite instantaneous and almost total. As a result, the capacity of the river to deal with flood discharges from its catchment has became grossly inadequate. At the Tun Perak Bridge, for instance, the channel capacity is about 180 m^3/s, while the magnitude of the 100-year flood peak had increased to 460 m^3/s. The sorry state of the river is thus sadly reflected each year when the banks and surrounding areas at this bridge become subjected to flooding.

Simply enlarging the river section and hence its capacity is not seen as an appropriate solution to the flood problem. Such works would involve land beyond the existing river reserves and in a tightly congested river front as in the city centre, would be exorbitantly expensive and quite unmanageable. Also, increasing the channel capacity at localized stretches in the city would not end the problem but merely relocate it elsewhere downstream. Consequently, the strategy adopted for flood control at KL city centre was to reduce the flood magnitudes passing through at the centre, rather than to increase existing the channel‘s capacity.

Several alternatives for doing so were looked at. One involved the construction of new dams in the river’s headwaters. However, this was not seen as a solution because the catchment contributing mostly to the flooding at KL are built-up lands in and around the city and at these locations, there were few suitable sites for dam construction.

Flood proofing the flood prone areas by embanking and/or raising ground levels was another alternative that was examined. However, this would not address the problem and in all probability will end up as a short-term solution.

Rainfall storage at source, also considered, was deemed unsuited because of the impracticalities of implementing it in an already fully developed city.

Finally, the provision of large storage facilities within city limits was explored. No suitable water body at the right locations could be found, nor were there easily available free space to build one.

What was ultimately chosen as most suitable was a flood bypass system in combination with regulated release. It could solve the problem at KL without passing it to another location. A flood bypass will function by re-routing floodwaters away from endangered areas by means of diversion channels or bypasses. It has long been one of the standard and conventional approach to flood control. A flood bypass’ effectiveness depends on :

i. understanding the flood cause
ii. finding the right location for diversion
iii. finding the right release point
iv. selecting a good route between the two
v. choosing the correct form for the conveyance.

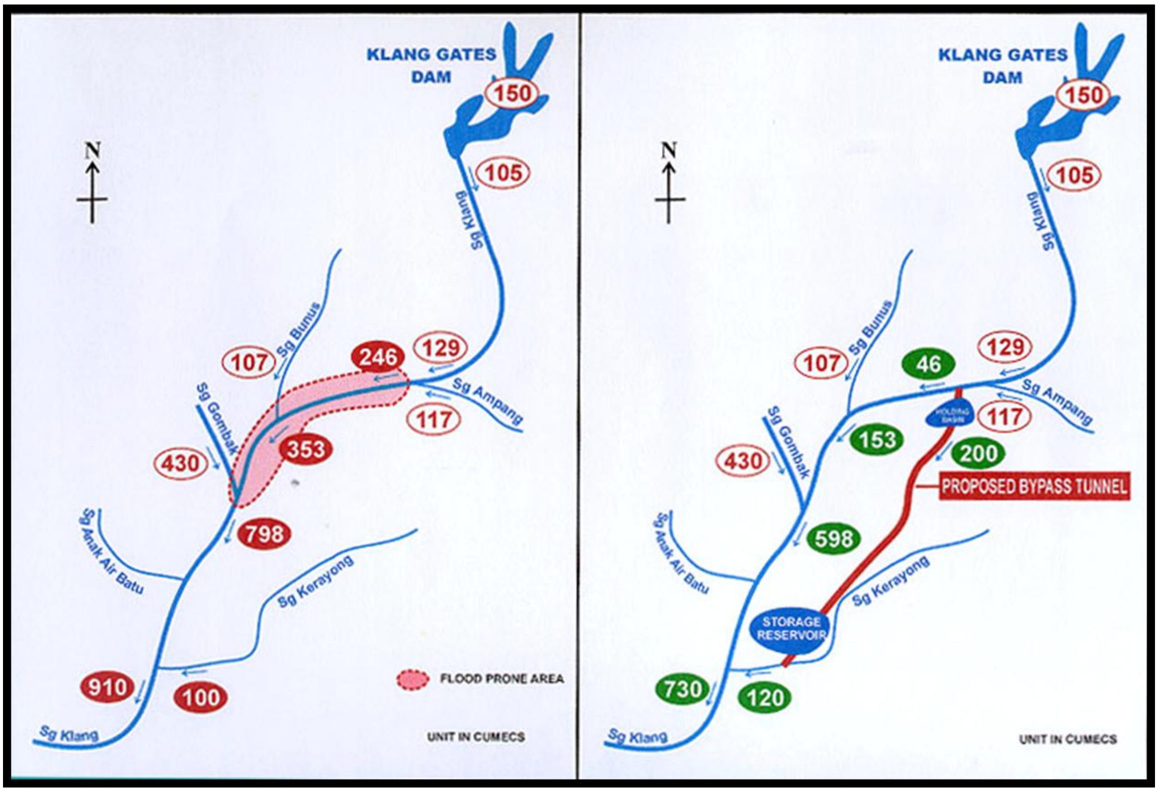
Item i) above is to ensure that the diversion will work and at the same time establish the amount to be diverted. Item ii) will confirm that the amount to be diverted is indeed available and that diverting it from this point would have the desired impact of flood control. If iii) is not properly addressed the flooding would be transferred to another location. Finally iv) and v) are important because they ensure that the diversion will do the job, is constructible and can be operated, all of which are important for a sustainable and cost efficient solution.

6.0 STORMWATER MANAGEMENT & ROAD TUNNEL (SMART)

At the city center, it is impossible to widen the river channel due to land constraints as development has taken place on both banks right to the edge of the river wall. Under such circumstances the flood water has to be retained upstream in ponds or diverted downstream by-passing the city center. The Stormwater Management and Road Tunnel (SMART) Project is designed to reduce the storm flow through the KL city center to a manageable quantity within the capacity of the river.

Under the SMART project, 280 m^3 of flood discharge will be diverted into the Kg. Berembang holding pond with an area of 8 ha and having a capacity of 600,000 m^3. The water will flow into a by-pass tunnel 9.8 km long and with an internal diameter measuring 11.8 metres. The total storage provided by the tunnel during diversion is 1 million m^3 and it will discharge into a storage reservoir of 23 ha at Taman Desa having a capacity of 1.4 million m^3. The effect of the bypass and the storages that can be contained within the system is to reduce both the flow through the city centre as well as the subsequent discharge back into the river system downstream of the city. The discharges passing through the city with and without the SMART project is shown below.

Without SMART Project **With SMART Project**



Part of the tunnel will be used for dual purpose viz. for flood and as a double deck motorway. This length of about 3 km lies in the middle section between Kampong Pandan and Sungai Besi. Junction boxes at these points will connect the ingress/egress to the tunnel.

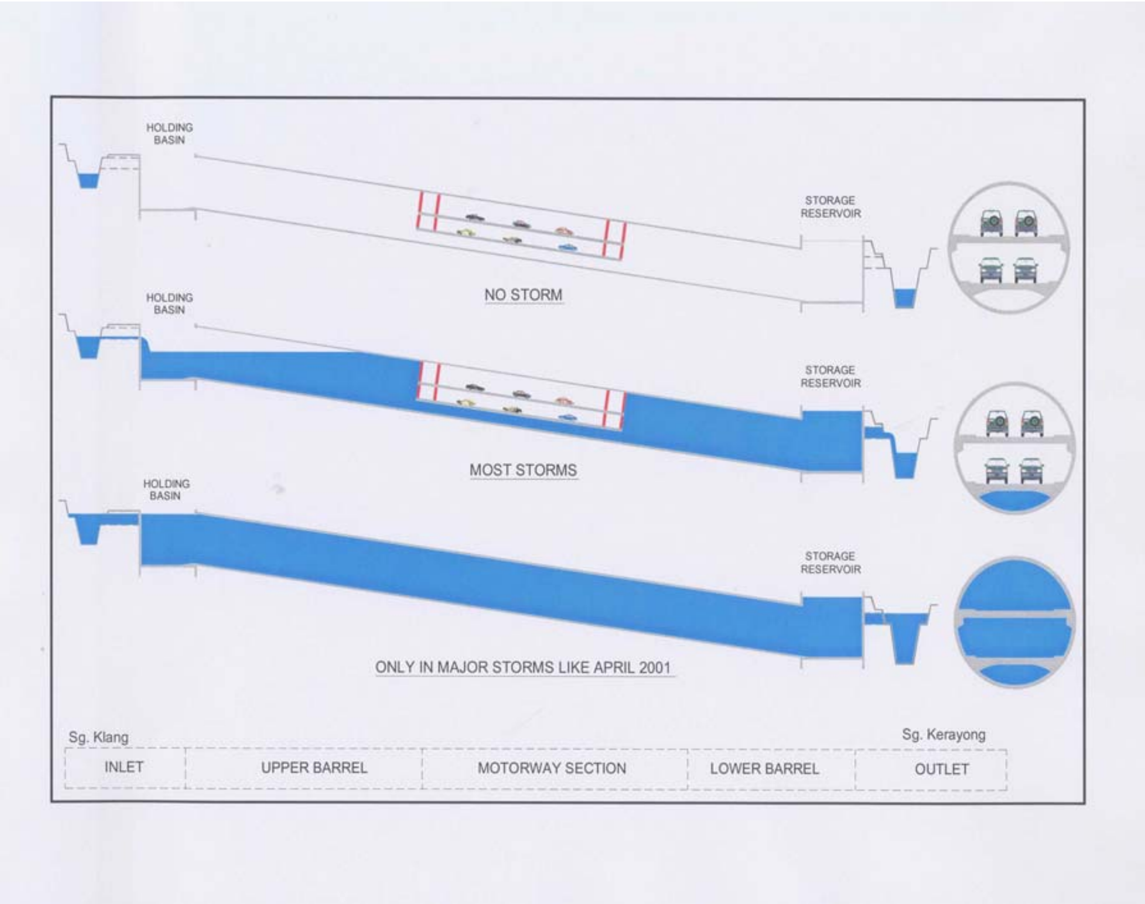
The SMART system will be operated based on the relationship between flood discharge at the Klang/Ampang Rivers confluence and the operation status of the motorway. When the flood discharge exceeds 70 m^3/s, the excess water will be diverted into the bypass tunnel and when it exceeds 150 m^3/s the motorway will be closed and the whole tunnel will be used for flood water discharge. This will reduce the flood level at Tun Perak Bridge to be below the surrounding ground level of 30 m.

6.1 Modes of Operation

There will be three modes in the operation of the SMART tunnel (see figure below). In mode I (no storm), which is the normal condition, the tunnel will be kept dry, as no water would be diverted into the system. Even so, the set of twin floodgates installed at either end of the traffic section would isolate this part of the tunnel from the other sections.

In mode II, (minor storms) some water will diverted into the tunnel but it would be confined to the lowest drainage chamber provided in the traffic tunnel. During such times, the set of twin floodgates at either of the traffic tunnel will continue to be kept shut, to ensure safety for the traffic in the tunnel. Each gate in the twin set is by design capable of sealing the traffic compartment. Nevertheless, for additional safety reasons, a twin set is provided for backup.

In mode III (major storms), a much larger discharge will have to be passed through the tunnel for which the full section of the traffic compartment will be required. During this operation, the tunnel will be closed to traffic and secured for flooding. Road gates placed at either end of the traffic compartment will prevent water in the tunnel from reaching the ground surface at the ingress/egress.



Mode I will be the normal situation for most days of the year. Mode II is expected to be operated perhaps eight to ten times each year. Mode III is likely to be operated once in a year or two years. During mode II or III situations, the diversion through the tunnel will not exceed 8 hours. Thereafter another 10 hours will be required to dewater the system and for cleanup operations. The cleanup and checks would take about 3 days before traffic is allowed back in the tunnel. Notwithstanding this, the component for stormwater management is designed to be ready in 24 hrs for handling the next storm.

7.0 CONCLUSION

The ongoing works under the Kuala Lumpur Flood Mitigation Project is designed to reduce the occurrence of floods in the city. Over the past three decades, the rapid pace of development in and around the city has exacerbated the flooding situation. As the main constraint to drainage lies at the heart of the city, it has become necessary to reduce the flood flow by introducing a flood bypass, viz. the Stormwater Management and Road Tunnel (SMART) project. Also, as the flood bypass will only be in operation for a few times in a year, the middle third portion of the flood tunnel has been converted for dual use, viz. for flood mitigation and traffic.

However to be effective in the long term the proposed program of structural works must be combined with the implementation of Integrated River Basin Management measures. The appropriate non-structural flood mitigation measures including land-use planning and development controls in floodplain areas have to be looked into seriously. If these measures are not implemented then the community will in one way or other end up paying for a higher cost in future flood mitigation works.