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KUALA LUMPUR: RE-ENGINEERING A FLOODED CONFLUENCE

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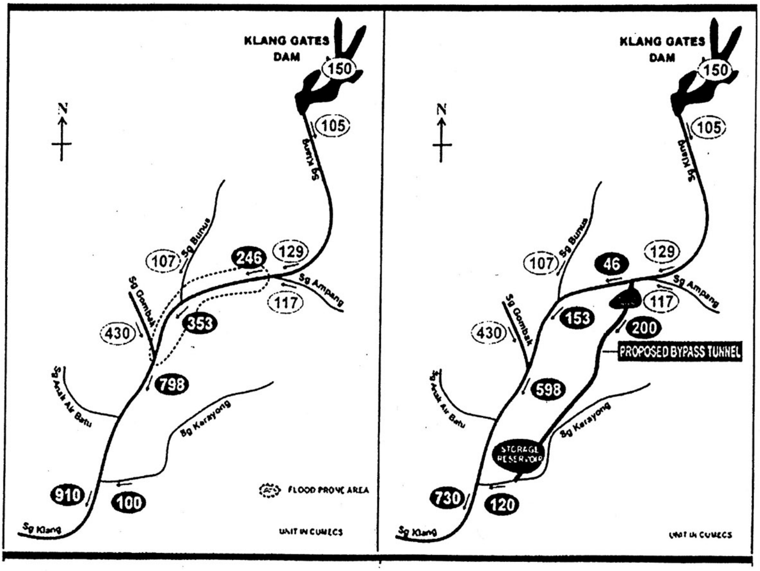
Without SMART Project **With SMART Project**



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Professor Chin Fung Kee Memorial Lecture – 2004

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SYNOPSIS

Kuala Lumpur or KL as it is more fondly called was founded in the late 19^{th} century as a tin mining settlement at the muddy confluence of the Klang and the Gombak Rivers. A century later it has become the nation's largest city, its capital 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. The rapid development of the last three decades has brought with it urban congestion, traffic gridlock and devastating bouts of flooding that have turned a muddy confluence (Kuala Lumpur) into a flooded confluence (Kuala banjir).

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 has been developed which incorporated a number of engineering options including upstream storage, poldering and pumped drainage, and the improving of the drainage capacity of the Klang River and its major tributaries. A decade later, this plan had been enlarged to cover the whole Klang Valley and modified to take into consideration the Government's decision to cancel the proposed Gombak Dam. 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 lecture will discuss the KL flooding problem and its causes, and trace the engineers' 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 dual purpose tunnel to handle both flood and traffic flow.

1.0 INTRODUCTION

The city of Kuala Lumpur (KL), also known as the garden city of lights, 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 Malaysia's largest city, and it has been the center of the country's economic development over the past 20 years. It is estimated that about 50 percent of the Klang River Basin has been developed for residential, commercial, and industrial use. It is densely developed and has a population of about 3.7 million people out of which 1.3 million people reside in the city. As a result of the rapid pace of development, occurrences of flash floods due to clogged drainage system and floods due to overtopping of river banks has become a common phenomena. The transformation of Kuala Lumpur into a modern metropolis center has brought along challenges for the engineers to have innovative engineering solutions.

2.0 TOPOGRAPHY

Hills, some of which with near vertical slopes and rising to 1430 meters, extend in all directions from Kuala Lumpur except southwesterly. As a result, much of the surrounding areas of Kuala Lumpur are built on hills and within the city the land rises gradually away from the river. 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 Klang River is 120 km long starting from the hills and ending in the sea. Of its two main 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. The earliest recorded 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 cost of damage was estimated to be in the region of RM 36 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

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.

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.

At the same time, the capacity of the river system has been reduced due to heavy siltation. The large volume of sediment (Tables 2,3,4) 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.

There are also constrictions to the river flow especially at 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.

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

5.0 FLOOD STUDIES

To better understand the situation, a number of flood studies have been carried out over the years. Some of the major studies include :

i) Kuala Lumpur Flood Mitigation Study, by the United States Bureau of Reclamation (USBR) (1981)
ii) Flood Mitigation of the Klang River basin Study, by JICA (1989)
iii) Klang River Basin Integrated Flood Mitigation Project Malaysia, by Kinhill in association with Ranhill Bersekutu Sdn. Bhd (1994)
iv) Impact of the construction of the PUTRA LRT on flood levels of Sg. Klang at Jambatan Lebuh Pasar, by MINCO (1996)
v) Sg. Klang Flood Mitigation Project Review Report, by Dr. Nik and Associates (DNA) (1996)
vi) Klang River Basin Environmental Improvement and Flood Mitigation Project, by Dr. Nik and Associates (DNA) (2001)

The **USBR** Study (1981) proposed the raising of the existing Klang Gates Dam by 3 meters and the installation of gates on the spillway. This would increase the reservoir capacity to about 36 million m^3 which is an increase of about **76 %** of the original reservoir capacity. The increase in capacity would also contribute to increasing the supply available for domestic and industrial water use. Hydrological studies indicate that the maximum probable storm would cause a maximum inflow to the Klang Gates reservoir of 716 m^3/s with a 3 day volume of 29.2 million m^3. Safety to the dam requires a maximum normal water surface elevation not exceeding 96.6 m.

The USBR study also recommended the construction of 2 more dams located on the Gombak River (12km north of the city) and the Batu River (12k north of the city), and flood channel works on the major tributaries. The dams were to provide flood control, trapping of sediment and develop municipal and industrial water use for the Klang Valley.

The **JICA** Study (1989) reviewed the existing flood mitigation plan for Kuala Lumpur and provided an assessment of the capacity of flood protection level of the various reaches of the Klang river system. It found that the stretch of the Klang River between Sultan Ismail Bridge to Sulaiman Bridge had a flood occurrence of between 10-25 year return period.

The study recommended :

1) Construction of Batu Retention Pond with a total area of 113.4 ha and a storage capacity of 2.7 million m^3
2) Construction of the Gombak Diversion Channel about 3.4 km long and capacity of 60 cumecs
3) Retain the use of Rasau Swamp as a natural retarding basin
4) Removal of the Puchong Drop Structure
5) Channel improvement of about 95 km in length for the Klang, Gombak and Batu Rivers
6) Construction of a poldering system and a pumping station in Kampung Baru
7) Reconstruction of the Tun Perak Bridge

With the completion of the river improvement works in the middle and the lower reaches of the Klang River, the flood protection level will be about 30 years return period for the middle reach and 100 years return period for Klang town. On full completion of all the above project components, the flood protection level will increase to 100 years return period for the whole river. The study also emphasized on the importance of controlling the discharges from the tributaries and to make use of the existing mining ponds in the Klang River Basin to serve as retention ponds for flood mitigation. It also singled out the natural retarding basin (Rasau Swamp) at Sg. Rasau in Shah Alam.

The **Kinhill** Study (1994) examined the problems in the Klang River Basin due to the existing and potential erosion and sedimentation. Sedimentation of the watercourse in the basin will continue unless effective land use planning, watershed management and specific erosion strategies are implemented. The study highlighted the benefits of Rasau Swamp as a flood and sediment detention basin. It also recommended the need to construct levee on both banks of the Klang River downstream of Shah Alam

The Study stressed on the need for co-coordinated approach between the Federal, State and Local Authority agencies involved in catchment management. The study determined the return period of floods occurring at Tun Perak Bridge at approximately 14 years. It predicted the 100 years flood profiles in the Klang River to be well in excess of those estimated when the Klang River channel was designed. It showed that the flood levels at

Cheng Lok Bridge and Lebuh Pasar Bridge exceeded the road surface elevations of 30.0m adjacent to Tun Perak Bridge on both banks of the Klang River.

In the **MINCO** Study (1996), the flood profile matched that of Kinhill study (1994). The study showed that the flood level upstream of Lebuh Pasar Bridge would rise with the construction of the Putra LRT. The calculated 100 years return period water levels are higher than those calculated when the channel was designed. A major cause of this discrepancy can be traced to the constrictions in the Klang River between Sulaiman Bridge and Tun Perak bridge namely:-

i) Constrictions at Kinabalu, Cheng Lok and Lebuh Pasar Bridges
ii) Underground Putra LRT tunnel at Lebuh Pasar Bridge
iii) STAR LRT platform at the Tun Perak Bridge

The study by **DNA** (1996) predicted an increase in flood discharges compared to those of Kinhill and JICA. This study had made allowances for future catchment development. A summary of the discharges derived from this study compared with the earlier studies is given in Table 5 below :

Table 5 Summary of Discharges

Location	**Study**	**100 yrs cumec**	**50 yrs cumec**	**10 yrs cumec**
Sultan Sulaiman Bridge	JICA(1989)	795	665	360
	Kinhill(1994)	798	655	406
	Dr. Nik(1996)	955	811	531
Confluence of Klang and Gombak Rivers	JICA(1989)	295	255	145
	Kinhill(1994)	353	297	193
	Dr. Nik(1996)	446	384	260

The 2001 Study by DNA envisages substantial future urban development continuing at a fast rate according to the 2020 "PELAWI II Strategic Plan". The study took into account of the previous percentage of land across the basin being reduced from 66% to 57.3% resulting in a 26% increase in impermeable areas.

The study identified two (2) forms of flooding in the Klang River Basin viz. :

i) Monsoonal type :- caused by long duration (3 t0 10 days) of low intensity (about 20 mm/hr) rainfall precipitating over a larger area. Floods caused from this type of rainfall are serious as it is widespread and long lasting.
ii) Flash floods :- caused by thunderstorms which are localized rainfall of very high intensities (>180mm/hr) and short duration (2 to 3 hours). The intense level of precipitation during the storms causes large volumes of water run-off into the drainage system and overloading them.

6.0 FLOOD MITIGATION WORKS

The early flood mitigation works were carried out by the Hydraulic Branch of the Public Works Department. In 1932 Drainage and Irrigation Department (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 up to Jalan Pekeliling, completed in 1960
- **v)** Improvement of the Gombak River, completed in 1969.

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 % 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. 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 a surface runoff from 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 107.3m. 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, additional lands for roads, services and other project functions would require a total land area of 411 ha. The Gombak Dam project was shelved due to social problems as about 1,110 families comprising of 4,523 people resided 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 (3.4km) 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.

The studies indicated that each of the above dam and reservoir can impound flood flows for all flood events up to 1 in 100 year return period. The improved channels of the 3 rivers will provide a capacity of 736 m^3 at Lebuh Pasar which is sufficient to protect the city from floods up to 1 in 100-year event. However, without the Gombak Dam the city can only be protected up to the 1 in 85 year to 90 year flood event and without the the storage dams the improved channels can provide flood protection to the Klang valley of only 1 in 55 years.

Table 6 Dams Statistics

	Klang Gates Dam	**Batu Dam**	**Gombak Dam**
Total Capacity	35.4×10^6 m^3	36.6×10^6 m^3	42.6×10^6 m^3
Inactive storage	3.2×10^6 m^3	4.2×10^6 m^3	5.4×10^6 m^3
Flood Control Storage	6.2×10^6 m^3	4.9×10^6 m^3	7.8×10^6 m^3
Conservation Storage	22.6×10^6 m^3	27.5×10^6 m^3	29.4×10^6 m^3

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/ sec each were installed.

The original project cost of the Kuala Lumpur Flood Mitigation Project was RM 1,272 million and was scheduled for completion in 2005. Up to the end of 2003 approximately RM 1,218 million has been spent. The scope has also been increased and the time of completion has been extended to 2007.

vii) **Flood Bypass :-** Re-routing floodwaters away from sensitive areas by means of diversion channels or bypasses is one of the standard approach to flood control. Its effectiveness depends on :

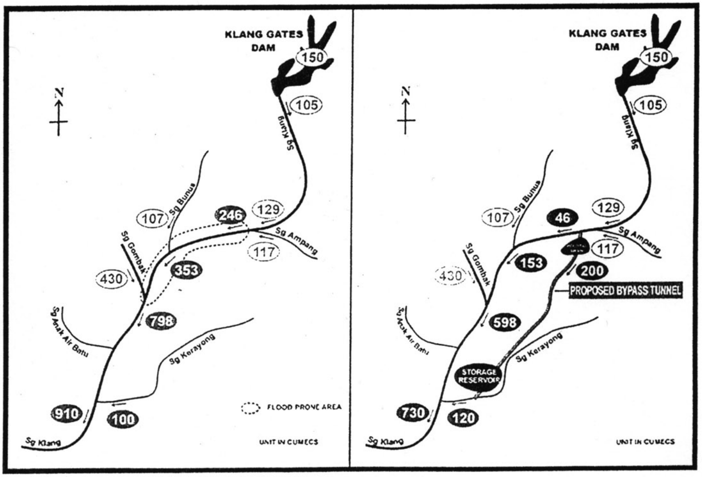
i. understanding the flood cause
ii. finding the right location for diversion
iii. finding the right release point
iv. selecting a good route between the two
v. choosing the correct form for the conveyance.

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 transfered 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.

At the city center it is impossible to widen the river channel due to land constrains 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 which has just started will reduce the storm flow into KL city center to a manageable size within the capacity of the river passing through.

Under SMART 280 m^3 of flood discharge can be diverted into the Kg. Berembang holding pond with an area of 8 hectares and having a capacity of 600,000 m^3. The water will flow into a by-pass tunnel 9.8 km long and 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 hectares at Taman Desa having a capacity of 1.4 million m^3. 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 cumecs the excess water will be diverted into the bypass tunnel and when it exceeds 150 cumecs 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.

7.0 INTEGRATED SOLUTIONS

As a result of the 1971 flood the DID has taken steps to rehabilitate and upgrade the river and drainage systems. Initially the concept was to go for the traditional method of rapid discharge. This involved improving the channels by lining them with concrete so that water will be discharged faster. Upstream storage facilities were also introduced by constructing dams and ponds which regulate the amount of water discharged downstream.

To remedy existing stormwater problems and to prevent the occurrence of new problems a combination of structural (curative) and non structural (preventive) measures had to be taken.

The structural solutions identified include:

i) Improvement of Klang River channel as well as the removable of Puchong Drop bridge and weir;
ii) Construction of Klang River levees at the lower reaches of the river where it is subjected to tidal influence;
iii) Construction of sediment traps before it enters the rivers.
iv) Tributary river channel improvement including the construction of a diversion channel from Bohol river to the existing pond;
v) Construction of flood bypasses, river diversions, poldering and construction of flood storage dams.

The use of structural flood control measures has proven effective in controlling floods and in some cases may be the only option available for built up areas. However, they are "hard" engineering measures that result in the widening and deepening of river channels together with the lining of the river banks, often at exorbitant costs.

More and more, the way forward is to approach the problem through an integrated approach, involving both structural and non-structural measures. Among the non structural measures proposed are:

i) Improve hydrological and topographic data as the basis for flood forecasting and warning system;
ii) Watershed management and land use planning practices to conserve soil reduce sediment overload in the river system;
iii) Minimizing runoff so as to limit the increase in peak rates of runoff

iv) Solid waste management and public education to reduce and eventually eliminate the dumping of solid wastes into the rivers.

v) Restriction of development and land use zoning

Whilst structural measures are a key component in reducing the impact of flooding on existing development, non-structural methods are more effective in preventing floods from occurring and with the aim of minimizing losses due to flooding. It is thus important to implement strong planning and building controls to ensure development is not permitted in the floodplains and highlands with >35° slope. New development should not impede the flows nor increase pre-development discharges. Erosion control should be effectively implemented mainly during construction. This involves the cooperation of the various government departments and the construction industry.

The effort to minimize additional runoff and increase on site water retention by gravel filled beds and trenches need to be adopted by new development. All future development should use the techniques of permeable driveways, porch ways front garden, parking, roadways and rainwater storage tanks in addition to making use of ponds for flood water detention or retention.

The implementation of runoff minimization techniques into urban development has been emphasized with the introduction of the Urban Stormwater Management Manual for Malaysia. (Manual Saliran Mesra Alam) which replaces the previous manual "Urban Drainage Design Procedure (1975).The Cabinet has directed this manual to be adopted throughout the country with effect from 1st January 2001. The conventional concept of rapid disposal has been replaced with concept of "controlling at source" in this manual.

8.0 CONCLUSION

The ongoing works under the Kuala Lumpur Flood Mitigation Project is designed to reduce the occurrence of floods in the city. 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.