

## Stormwater Management and Road Tunnel (SMART) a Lateral Approach to Flood Mitigation Works

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**ABSTRACT:** Kuala Lumpur is the nation's hub for commerce and business. Large corporations and businesses are situated in this city. To meet their growing and sophisticated demands the city is being re engineered. The changes particularly since the eighties have been quite drastic. Its land use impact has rendered incapable the city's flood management facilities to perform. Conventional means to mitigate the problem are no longer effective. A radical approach was necessary that led to the formulation of SMART. SMART is the flood management solution for 21<sup>st</sup> century KL. This paper discusses the KL flooding scene, early actions of government to contain it, why modification to the plan was necessary, and what is the present day solution being implemented.

### INTRODUCTION

The city of Kuala Lumpur (KL) is located at the confluence of the Klang and the Gombak Rivers. It was founded in the late 19<sup>th</sup> century as a tin mining settlement. Over the years, KL has grown to become Malaysia's largest and most important city.

The transformation of KL into the ultra modern metropolis it is today has not been without trials and challenges to Government. As development kept changing the face of the city, existing infrastructures came regularly under pressures to service demands beyond their design limits. Repeated Government intervention to upgrade and modernize affected facilities was called for and these received the constant attention of planners in various Government agencies. It led to the implementation of many government-sponsored programs to improve services in the city.

One such program, the subject of this keynote address, is KL's main drainage system. The urbanization of the catchments in and around the city particularly over the last two decades has caused much upheaval in the hydrological regime. Today's flood runoff is many fold that which the river system serving KL is able to deal.

Government has invested in a phased program to rehabilitate the existing drainage infrastructure. The initial phase involved the construction of upstream storage facilities to reduce flood magnitudes in the city and the improvement of channel capacities to speed up the passage of the flood wave through the city. There is however, a limit to the application of such solutions and it became quite apparent in the late nineties, that this limit was being reached. A com-

pletely new approach was necessary for flood control in KL.

This paper will discuss the development of this approach. It will:

- i. identify the nature of flooding in KL,
- ii. outline government's initial counter measures,
- iii. explain their limitations, and
- iv. describe the current proposal for flood mitigation.

### KL'S FLOODING PROBLEM

#### The Klang River System

KL is situated in the mid upper reaches of the Klang River. The river drains a catchment approximating 1,288 sq km. It originates from the main range at an elevation of 1,330 meters above mean sea level and traverses a distance of nearly 120 km through the two States, Selangor and Wilayah, before discharging into the Straits of Malacca.

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. The principal tributaries of the Klang River System, namely the Batu, the Gombak and the Ampang rivers join the main river at this stretch.

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 dyked at many locations and provided with improved drainage to enable the cultivation of crops such as rubber, oil palm and coffee. In recent times there is observed a movement to buy over the estate lands for development into new townships and residential areas. This process of landuse 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.

About 3.75 million people presently populate the river basin.

#### KL's Flood Trends

KL straddles the confluence of the Gombak and Klang rivers. The area is known as the Upper Klang Valley and is the most heavily urbanized and densely populated part of the country. Its central location and stature of being the nation's capital city, is a magnet for businesses and commercial enterprises to set up base and keep expanding on their activities. They in turn attract the developers who relentlessly engage in a never-ending program of providing more and more office spaces and housing into what is already a very congested.

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.

Free land to undertake drainage improvement works is scarce in the city. Vacant lands and greens are targets for buildings and infrastructure development. Pressure is tremendous for existing reserves to be shared for multiple uses and they are fast becoming overcrowded. A number of drainage reserves at key locations have already been encroached. KL has experienced fourteen numbers of major flood incidences in its history (Table 1). Of these seven have occurred in the last 8 years.

The earliest recorded incident was the flood of 1926. The largest in recent history was the flooding in 1971. This particular event was widespread and affected a number of other States in the country as well. More recently, there have been occurrences of flash floods in the city. They descend with hardly any warning and totally upset city routine.

Table 1. Flooding Incidences in KL City

Period	No of times	Dates
Before 1950	1	1926
1950 to 1975	1	1971
1976 to 1985	1	1982
1986 to 1995	4	1986, 1988, 1993, 1995,
1996 & now	7	1996, 1997, 2000, Apr 2001, Oct 2001, Jun 2002, Jun 2003

The increasing trend of the flood magnitudes is best illustrated in the measurement of annual flood discharges taken at Sulaiman Bridge (Figure 1).

#### GOVERNMENT'S MASTER PLAN FOR FLOOD CONTROL IN KLANG RIVER BASIN

##### Flood Study

In 1987, Government undertook a Study to understand the flood problem in the Klang River Basin and how to respond to it.

##### Flood Analysis

The Study identified two forms of flooding that affect the Klang River Basin.

The first was the monsoonal type flooding caused by long duration (3 to 10 days) of low intensity rainfall (20mm/hr or so), precipitating over a large area. Characteristically the resulting flooding is also widespread. The flood of 1971 was a monsoon type flooding.

Flooding of the second type is caused by thunderstorms which are localized rainfall of very high intensities (>180 mm/hr) and short durations (2 to 5 hours). The intense level of precipitation causes large volumes of storm run-off even from small catchments, which often leads to drainage and river systems in the localized areas being completely overloaded. This causes what is termed as flash flooding. As the name suggests flash floods are quick to manifest and equally swift to subside.

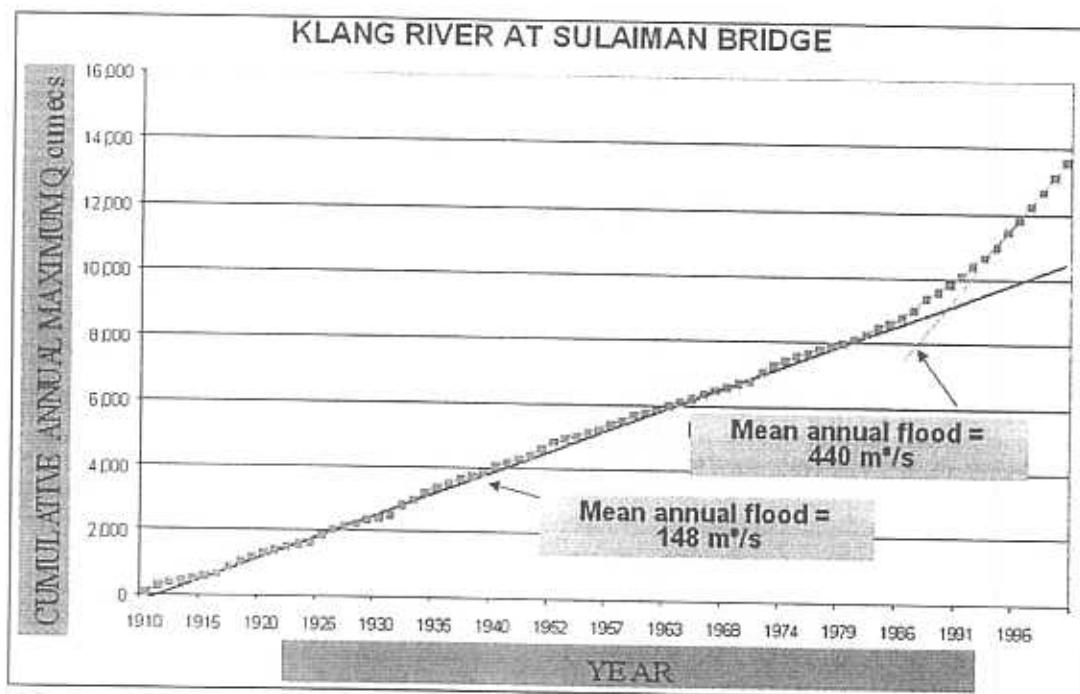


Figure 1. Increasing trend of annual flood discharge at Sulaiman Bridge

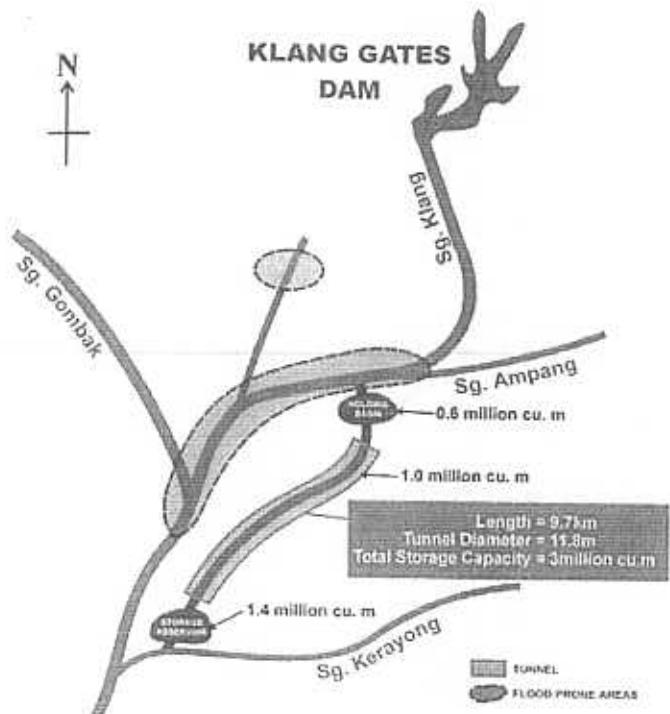


Figure 2. Stormwater management and road tunnel (SMART)

The Study identified that the form of flooding frequently experienced in KL is the flash flood and it can happen several times each year. Areas prone to flash flooding are shown in Figure 2.

#### Flood Causes

The Study attributed the escalation of flood incidences in KL to the following factors:

- i. urbanization causing increased runoff rates
- ii. development encroaching into flood plains and drainage corridors resulting in loss of flood storage
- iii. failure of localized drainage improvement works to extended sufficiently downstream bridges and culverts becoming constriction points because of increasing levels in flood discharges
- iv. siltation in existing channels from indiscriminate land clearing operations

#### Recommendations

The Study recommendations to Government were:

- i. a comprehensive flood mitigation plan for the entire Klang River Basin is necessary
- ii. its implementation should be phased, with the early stages addressing the flood problems in the Upper Klang Valley

- iii. during the implementation phase periodical monitoring is necessary and midcourse changes introduced as and when deemed necessary
- iv. guidelines have to be prepared on development particularly on how this activity's adverse impact on land and the environment can be kept under control.

#### Government's Response to Flood Study

The Government's follow up on the Study was immediate. Plans were prepared and approval given for the implementation of the Klang River Basin Flood Mitigation Project, KRBFP for short (Figure 3). It was designed for flood protection standard of 1 in a 100-year.

The Project strategy was:

- i. provide flood detention facilities in the headwaters where feasible
- ii. undertake channel improvement works at flood prone locations
- iii. build flood walls for protection of important flood prone low grounds complete with the provision of pumping facilities for hinterland drainage
- iv. implement inter-basin transfer for flood control if this were feasible

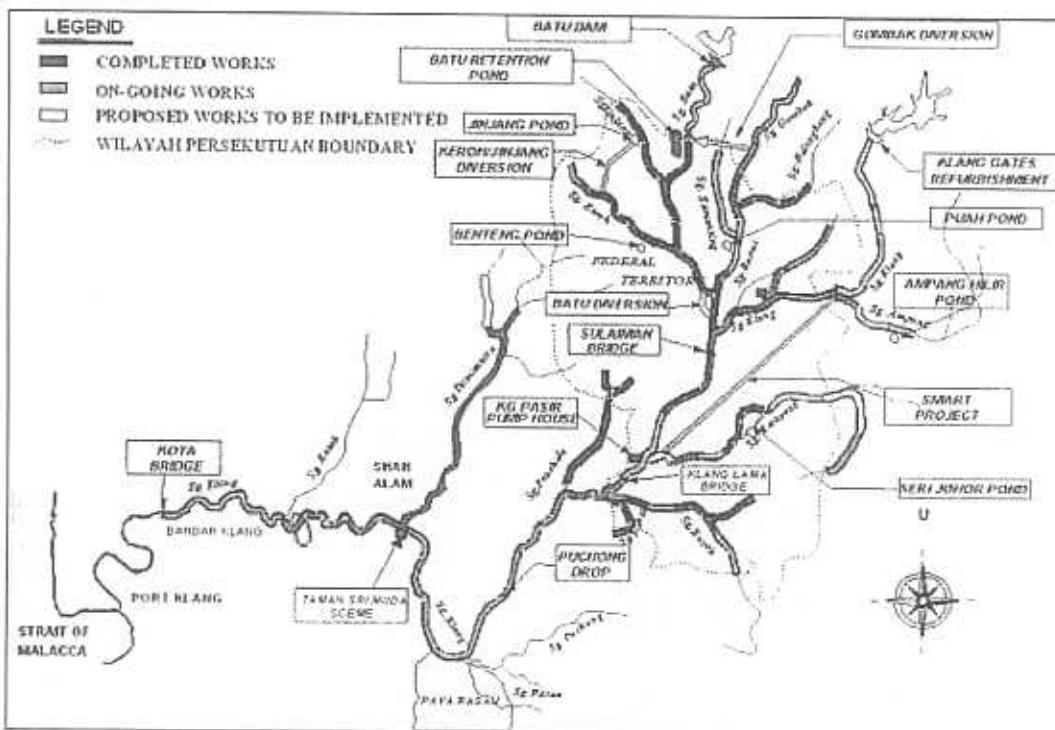


Figure 3. Klang river basin flood mitigation master plan (status of implementation).

### Klang River Basin Flood Mitigation Project (KRBMP)

Works identified under the KRBMP are:

#### Phase I:

- i. Raising Klang Gates dam for flood storage
- ii. building Batu dam for flood detention at headwaters of Batu River
- iii. carrying out river improvement works at priority locations (47.3km)

#### Phase II:

- i. construction of Batu Detention Pond Facility
- ii. construction of the Gombak Diversion Channel
- iii. conversion of swamps to Flood Retarding Basins
- iv. removal of Puchong Drop
- v. channel improvement works at Klang, Gombak and Batu Rivers (94.7 km)
- vi. rehabilitation of 10 numbers bridges in KL city

Phase I works are essentially completed. Phase II is presently under implementation and should be fully implemented by 2005.

#### Midcourse Appraisal of the KRBMP

During implementation of the KRBMP, a series of flood events hit the city between 1996 and 2000. It called to attention a need for urgent review of the Project.

The review showed up that:

- i. flood magnitudes in the city had further escalated
- ii. this was largely due to the intensity of land development.
- iii. the computed 100-year flood peak at Tun Perak Bridge is now 460 cumec instead of the original 353 cumec on which the KRBMP design had been based.
- iv. new points of constrictions had emerged in the river particularly along the stretch upstream of Masjid Jamek
- v. these were related to infrastructure development that encroached into the river corridor.

A model analysis carried out demonstrated that the 100-year flood level at Tun Perak Bridge would be 1.76 meter higher than the original design level of 9.34m LSD (Table 2). The ground elevation at this location was only around 30.00mLSD.

Table 2.  $Q_{100}$  Head Loss at Selected Bridges in KL

Name of locations	Head Loss (m)
LRT platform at Tun Perak Bridge	0.64
Kinabalu Bridge	0.47
Putra Underground LRT	0.27
Old Lebuh Pasar Bridge	0.25
Cheng Lok Bridge	0.13
total	1.76

These review findings formed the basis that lead to the formulation of SMART.

### STORMWATER MANAGEMENT & ROAD TUNNEL (SMART) FOR KL

#### Development of SMART

Over the course of developing SMART, a number of flood control options were considered. These are discussed below.

#### Upstream Storage

In this option dams are constructed upstream of the city to detain floodwaters and attenuate the flood flow into the city. Two such facilities have in fact been constructed under Phase I of the KRBMP (Figure 4).

The first involved the raising of the Klang Gates dam, which regulated the catchment of the upper Klang River. The second was the construction of the Batu dam to regulate the headwaters of the Batu River.



(a) Batu Dam



(b) Klang Gate Dam



(c) Sg. Klang at Masjid Jamek

Figure 4. Facilities for the flood mitigation projects in Klang River

The operation of both these facilities reduced the extent of unregulated catchment that discharged through KL city (Table 3).

A third such facility to control the Gombak River could not be constructed because of land acquisition issues. Apart from the above two, no other suitable sites for flood detention dams could be found.

#### Channel Improvement Works

Channel improvement entails river widening, deepening and alignment enhancing works sometimes with channel lining included as well. A comprehensive program of such works was drawn up for the Klang River under the KRFMP, from upstream of Kuala Lumpur down to Klang town (Figure 3). Some of these works are already done (Figure 4). The balance would be carried out in Phase II of the project.

Further improvement in this regard, particularly within city limits is not considered feasible, principally due to land constraints.

Table 3. Unregulated Catchments Draining Through KL

River	Catchment Area (sq km)					Location
	Total	Unregulated (%)	Land status			
Gombak	270	205 (76%)	Built-up	13	82	Batu Gombak
			Natural	5	53	Gombak
Klang	195	119 (61%)	Built-up	70	17	City
				90	17	Bunus
				32	24	Klang Ampang
			Natural	29	9	Klang
				20	24	Ampang

#### Embanking &/or Filling Low Grounds

Embanking as a means for flood proofing has been tried with quite some measure of success at Kampong Baru and Taman Sri Mudah.

In this application the flood levels are not lowered, instead flooding is prevented by the construction of floodwalls or by raising the affected grounds to above the flood heights. The latter is not only expensive but may also prove impractical in an already heavily built-up area. The application of the former usually requires the provision of pumping for hinterland drainage and this can be a substantial cost to the project. More importantly, both options do not address the cause of the flooding; flood elevations will therefore keep on rising and eventually negate the effectiveness of these measures.

For reasons explained the use of this approach was also dropped unless driven to necessity as a last ditch measure.

#### Storage at Source

Rainfall storage at source is being promoted as the flood solution for the future. In its application, rainfall is detained as it falls and released into the drainage network in measured amounts.

For the system to work individual houses and buildings will have to provide insitu storage for holding rainwater. It is important that these tanks be emptied in between storms to prepare for the next storm. Such storage can also be provided on a collective basis as in the case of a group of buildings in a sub basin. In these instances, parks, recreation grounds and sports field are sometimes used by suitable design to perform this function. Although in theory the idea is

What did stand out as suitable was a flood bypass system in combination with regulated release. It could solve the problem at KL without passing it to another location.

### The SMART Project

#### *Project Feature and Operating Rules*

The principal system components of SMART and their functions are described below.

Flood flows into the city are reduced by diversion at the Klang/Ampang confluence (Figure 2). The diverted water is passed through a bypass system and released downstream of the city. The point for the release is the Kerayong River about 1,800 meters above its confluence with the Klang River. To avoid downstream flooding, the release is regulated. This action of regulation and release also helps reduce on the storage that would otherwise have been required. An abandoned tin mining pond in the path of the bypass route is used for flood storage. By designing the bypass for gravity flow, operational costs are minimized.

Because the terrain between the points of diversion and release is quite undulating, it was not possible to use an open channel for the bypass. For this reason, a tunnel had to be selected. The project is designed to provide KL with a  $Q_{100}$  protection. This required the use of a very large bore tunnel for the bypass. To use the tunnel efficiently therefore, three categories of storm magnitudes have been identified and operation rules applied for each.

- i) Category 1 Peak at Klang/Ampang confluence not exceeding 70 cumec
- ii) Category 2 Peak at Klang/Ampang confluence above 70 cumec but not exceeding 150 cumec
- iii) Category 3 Peak at Klang/Ampang confluence above 150 cumec but not exceeding 300 cumec

In the case of Category 1 storm, the entire flow in the river is allowed into the city. For storms of this magnitude therefore the bypass is not activated.

If the storm is identified as a Category 2 case, the flow in the river is allowed into the city until the discharge reaches a level of 70 cumec. Thereafter the flow into the city is throttled down and kept at 50 cumec by activating the diversion. When finally the storm subsides and the incoming river flow reduces

to 100 cumec, diversion is stopped and all discharge once again allowed into the city

For Category 3 storm, the operating rules are a little more complex. As before, no diversion would be necessary, until the flow at the Klang/Ampang confluence reaches 70 cumec. Thereafter diversion is activated and the downstream flow throttled down to 50 cumec. As the storm intensity increases and the discharge at the confluence reaches 150 cumecs, the downstream flow is further reduced to 10 cumec.

This setting is maintained until after the storm has peaked and the flood begins to subside. Observation will then focus on the discharge at Tun Perak. When a flow of 150 cumec is first observed at this point, the downstream release at the Klang/Ampang confluence will be stepped back up to 50 cumec. This action will initially create a slight increase in discharge at Tun Perak. A little later, however a fall would be observed as the flood continues to subside and when the flow at Tun Perak drops below 150 cumec a second time, the downstream release at the diversion weir will be increased to 100 cumec. Flow diversion will continue until the flow at the confluence is less than 100 cumec whereupon the diversion is deactivated and discharge allowed into the city

For most days in the year, conditions in the river would be such that no diversion would be required and the tunnel is dry. Category 2 & 3 storms can happen about ten or so times each year. During such occasion, water is taken through the tunnel for duration not exceeding twelve hours. To capitalize on this factor and for cost effectiveness, a dual purpose tunnel is designed, one that can take in traffic when dry and used for flood discharge when this need arises. Hence the name SMART or Stormwater Management and Road Tunnel.

#### *Hydraulic Components*

There are principally three hydraulic components to SMART namely (Figure 2):

- i. the holding pond
- ii. the diversion tunnel
- iii. the storage & release system

#### *Holding Pond*

The holding pond is the head of SMART that draws water from the river and passes it into the tunnel. It is located on the left bank of the Klang River at the Klang/Ampang confluence (Figure 5).

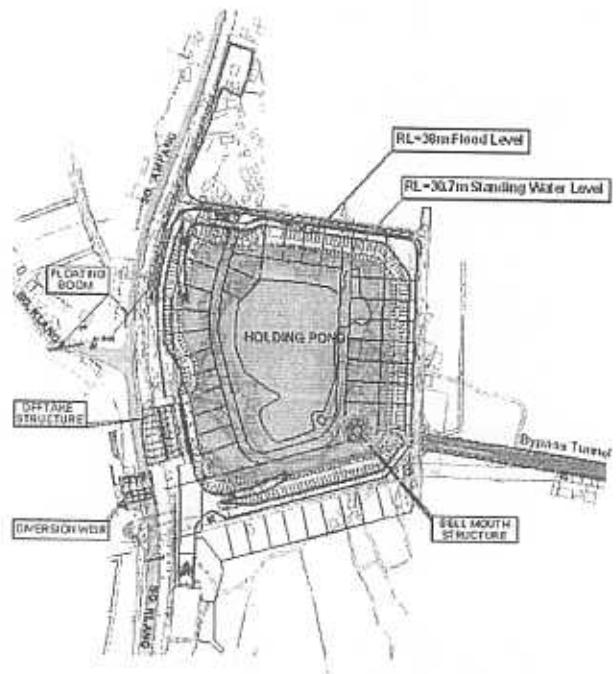


Figure 5. Holding Pond

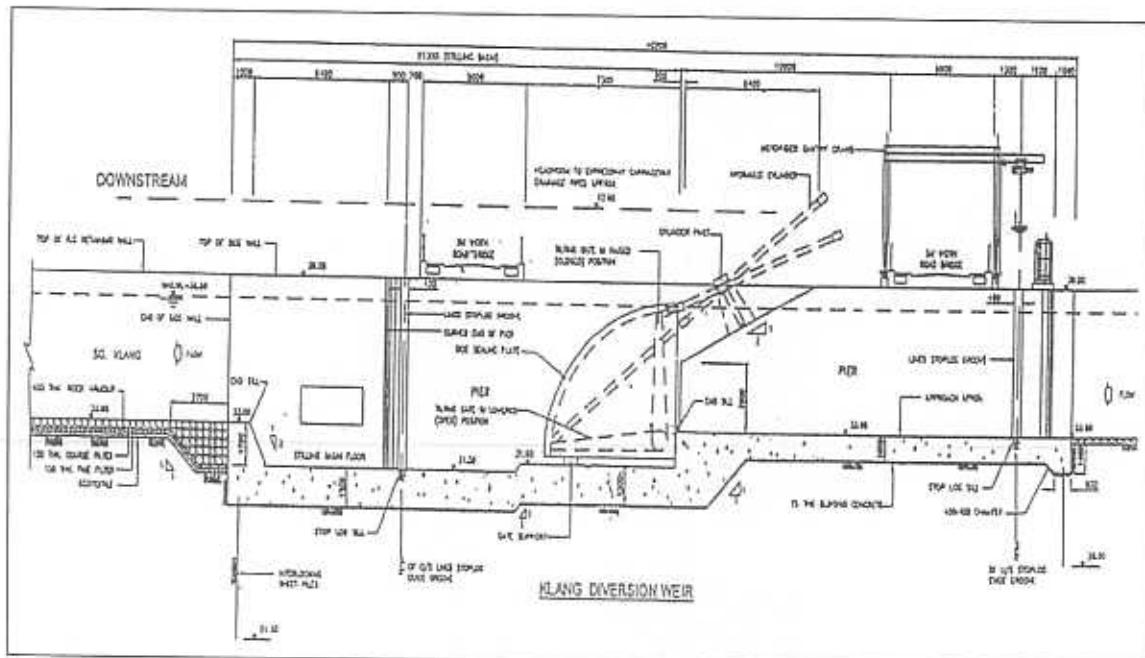


Figure 6. Klang diversion weir

The system comprises four structures:

- i. the diversion weir (gated tilting)
- ii. the offtake structure (gated vertical)
- iii. the holding pond
- iv. the bellmouth weir (ungated)

During diversion, water in the Klang River is drawn into the holding pond by closing the diversion weir gates and opening the offtake gates. As the water

fills the pond and reaches a certain elevation it is allowed to spill into the tunnel via the bellmouth weir.

The system is based on a design to manage a maximum flood discharge of 300 cumec at the Klang/Ampang confluence by diverting 290 cumec into the tunnel and allowing 10 cumec to pass through into the city.

The holding performs two functions:

- i. it holds water until the tunnel has been readied for flood discharge
- ii. it prevents entry of foreign material into the tunnel

#### (1) Diversion Weir

The diversion weir is a four bay structure fitted with tilting gates that have hydraulic arms to operate the tilt. Under normal conditions of flow, when the river is not being diverted, the gates sit flush with the riverbed. If diversion becomes necessary, the gates will be raised, thereby lifting the water level in the forebay to above the spill height of the offtake structure (Figure 6).

The invert of the diversion weir is 33.00mLSD to match the existing channel bed. The tilting gates are 6m wide and 5m tall.

A stilling basin is provided downstream of the tilting gates to ensure that the energy from the drop is dissipated before the water leaves the structure. The length of the stilling basin is 14m. It was derived based on design guidelines for a USBR impact block type basin. This choice is appropriate since the flow through the basin is quite substantial.

Provisions have also been incorporated for stoplogs at the upstream and downstream end of the structure. This feature enables any particular bay to be closed off should the gate fail to raise and also to facilitate de-watering if this were required for routine maintenance.

The river channel at approach and exit is widen and realigned to fit the dimensions of the diversion structure. Also provided are riverbed protections at both ends of the structure to control scour. During flow diversion the tilting gates is constantly adjusting so as to keep the flow into the city at a constant level and as per setting (10, 50, or 100 cusec).

#### (2) Offtake Structure

The Offtake is an 8-bay structure sited on the left bank of the Klang River immediately below its confluence with the Ampang River. It is fitted with vertical roller gates each measuring 6.00m wide and 3.50m tall.

It is designed to pass a maximum of 300 cusec into the pond and to verify this physical modeling was carried out. The floor at the structure's entrance is constructed to an invert level of 33.50mLSD (i.e. 500mm above the riverbed to discourage the sediment bed load from being drawn into the holding pond). A little distance behind the entrance, the floor

rises to a crest at 35.00mLSD. The gates are located at this point.

To dissipate energy and reduce the velocity of flow as it enters the holding pond a steep glacis is provided downstream of the crest and a short stilling basin connected to it (invert level at exit 27.30mLSD). For further protection against erosion, a short length of rock armour is also placed at the end of the stilling basin at the exit of the structure.

The flow, after passing over the weir crest, will enter the hydraulic jump basin by dropping down a sloping glacis. To avoid the tendency for the water to spring away from the floor and thereby reduce the surface contact pressure, a convex curved vertical profile of the glacis has been designed.

Due to space constraints, the short Type III basin with two rows of energy dissipation blocks was chosen for the stilling basin design. Under normal conditions, the gates are kept closed. When diversion is necessary, they would be fully raised and the river water, raised by the diversion weir, spills into the holding pond.

#### (3) Holding Pond

The holding pond is a 9.4 ha open cut storage basin that can store 600,000 cubic meter of water between its low water elevation of 29.70mLSD and maximum operating elevation of 38.00mLSD. The invert of the pond is built to 27.30mLSD giving it a dead storage of 2 meters for siltation.

At normal times, when SMART is not diverting water, the water level in the pond is maintained at 29.7mLSD. When diversion is activated, water level in the pond would buildup to level 34.00mLSD and then start spilling into the tunnel via the bellmouth weir. During such times, the pond would fill to a maximum elevation of 38.00mLSD.

Maintenance operations to remove silt from the pond are estimated to be necessary at 5-year intervals. To facilitate this, special features for machinery to access the pond have been incorporated in its design.

Other features of design incorporated in the holding pond sub system are:

- i. a floating trash boom in the river, upstream of the off take,
- ii. trash screens in front of the off take and bell-mouth structures.

Baffles are provided in the holding pond to increase water circulation and encourage sedimentation in the pond.

The form for these baffles was developed through mathematical model analysis and they would keep sediments down to 0.01mm from entering the tunnel. Materials finer than that will however pass through and be flushed through the system into the receiving river below.

(4) Bellmouth Weir

The bellmouth weir is an 8-bay structure connecting the holding pond to the upstream end of the tunnel. Its purpose is to delay the entry of water into the tunnel until preparations for it have been completed.

The structure comprises eight separate straight weirs arranged radially about a central stilling well (Figure 7). The spillway is an ogee weir with the crest at 34.00mLSD. By this setup a storage of some 300,000 cubic meters of water is possible in the holding pond before the tunnel starts to take in water. At peak flow, the structure has the capacity to discharge 300 cumec into the tunnel whilst 600,000 cubic meters is held in the holding pond at 38.00mLSD.

A hydraulic model study was undertaken to verify several aspects of the prototype's performance. The conclusions of the study and its follow up are discussed below:

Location	On the positioning of the structure, the study confirmed all edges of the structure were sufficiently far from the banks of the holding pond to ensure free circulation and therefore equal flow distribution over the eight radially placed intakes.
Hydraulic performance	On the stilling well design, the study showed that the flat floor caused a head loss of 0.81m at 300 cumec through the weir. This could be brought down to 0.73m if the floor were rounded and lowered by 1m. The modification was adopted and the stilling well floor is now lowered to 15.17mLSD.

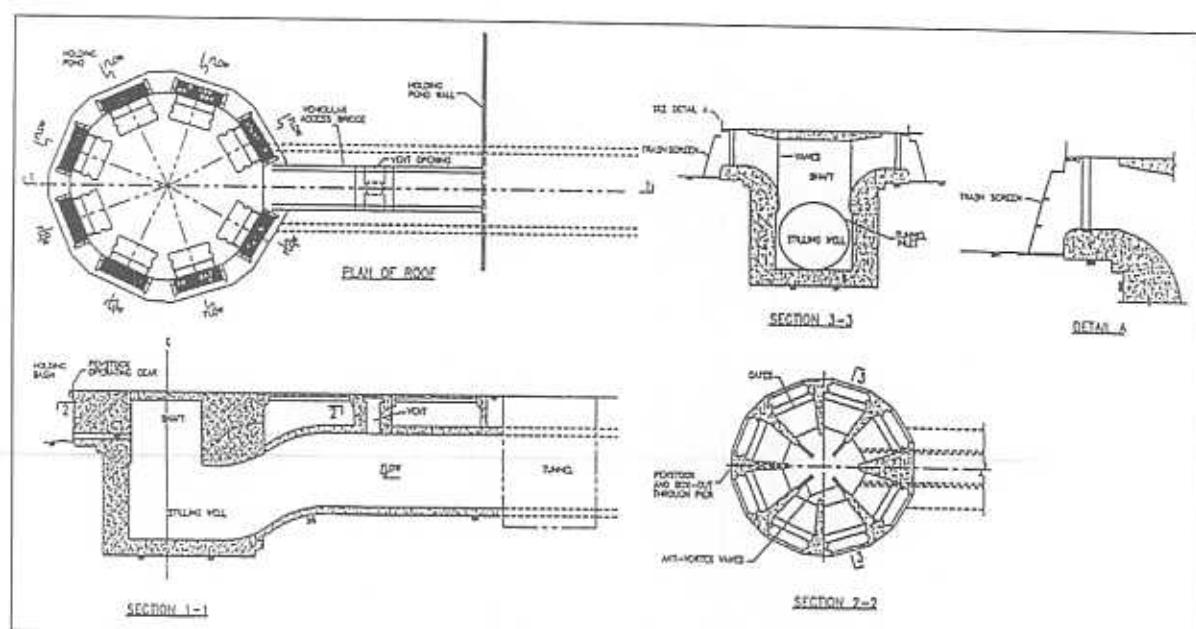


Figure 7. Bell mouth intake structure at the holding basin

### Flow characteristics

On the design of vortice vanes, the study demonstrated that the design was not effective against vortices being formed in the stilling well unless the vanes were heightened to 38.00mLSD; this modification has since been incorporated in the prototype.

### Venting

Finally, on air entrainment, the study

demonstrated that venting as provided at the start of the tunnel is in-fact effective.

### *The Diversion Tunnel*

The Diversion tunnel is the bypass conduit that connects the holding pond to the storage reservoir at the Desa Water Park. It is about 9.8 km long and has an

internal diameter measuring 11.8 meters. The total storage provided by the tunnel during diversion is 1 million cubic meters

The tunnel is built to an invert of 21.55mLSD upstream and 8.22mLSD down. For most of its alignment the tunnel follows existing roads in the area. This was decided upon to save on land acquisition as the cost of it otherwise would have been quite prohibitive (Figure 8).

Only part of the tunnel is used for dual purpose. This length of about 3 km lies in the middle section between Kampong Pandan and Sungai Besi. Junction boxes at these points connect the ingress/egress to the tunnel.

The cross section at the traffic length of the tunnel comprises three compartments (Figure 9). The top two are for traffic whilst the lowest is used solely for drainage. However, during conditions of certain storms, both the lower and the traffic compartments would be required for water passage. At these times, the tunnel would be sealed from traffic before it is flooded.

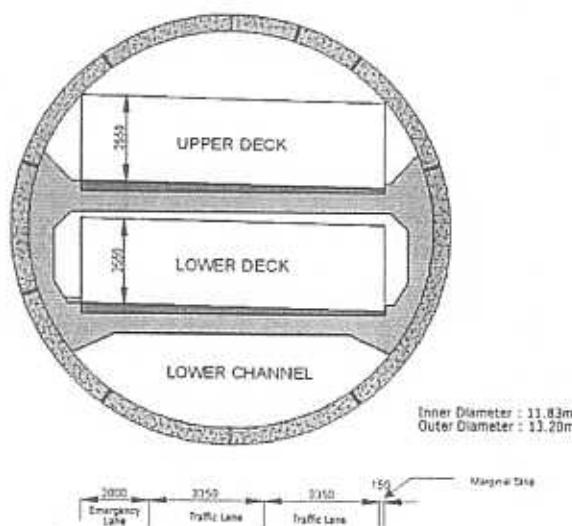


Figure 9. Motorway tunnel cross section.

#### (1) Tunnel Flood Gates

Flood gates installed in the junction boxes keep the traffic tunnel either dry or flooded as required during operation. The arrangement of the gates and the junction boxes are shown in Figure 10. All gate installations will withstand a water pressure head of 14.5m. The two service gates are designed to operate under unbalanced conditions. The emergency gate is not. A bypass is therefore provided around the emergency gate to flood the gate chamber and enable the

gate to be opened and shut under balanced conditions.

A pair of hydraulic cylinders lifts the gates. Each is provided with its own hydraulic drive unit. As a further safety measure, each drive has two pumps and two electric motors, one on duty and the other as standby.

To study the flow pattern during gate operation, physical modeling was undertaken. Through this measure, baffle walls of various heights, placed at different distances were investigated for their effectiveness in dissipating the energy downstream of the gates. Based on the findings from this study the final form for the buffer wall was decided.

Mathematical modeling was also carried out to determine discharge capacities and flow velocities at different stages of the operation. The results showed that the average full area velocity in the tunnel is 3 meter per second. However, during gate operation this can peak up to almost 5 meter per second in localized areas (Table 4). To withstand these velocities, the tunnel is lined with concrete of grade 60 standard.

Table 4. Tunnel Flow Velocities

Section	Full area of flow (m <sup>2</sup> )	Velocity m/s	
		Steady flow	Transient flow
11.8 dia tunnel	109	3.0	4.9
Upper road deck	36	2.5-3.2	4.7
Lower road deck	26	2.5-2.6	4.6
Lowest channel	19	2.1-3.0	4.9

An elaborate venting system is incorporated in the tunnel. This ensures that escaping air as the tunnel fill is not trapped and that the flow is uninhibited. The vents are located in the tunnel at the inlet, between the entrance and the first junction box (at 1 km interval), at several positions in the junction boxes, at several positions in the vent shafts, and at the tunnel exit structure.

Depending on their position, these vents perform different functions, viz:

- i. to expel air during tunnel filling,
- ii. to avoid air entrainment
- iii. to check air pocket buildup at high points
- iv. to provide ventilation at gate locations
- v. to act as surge shaft

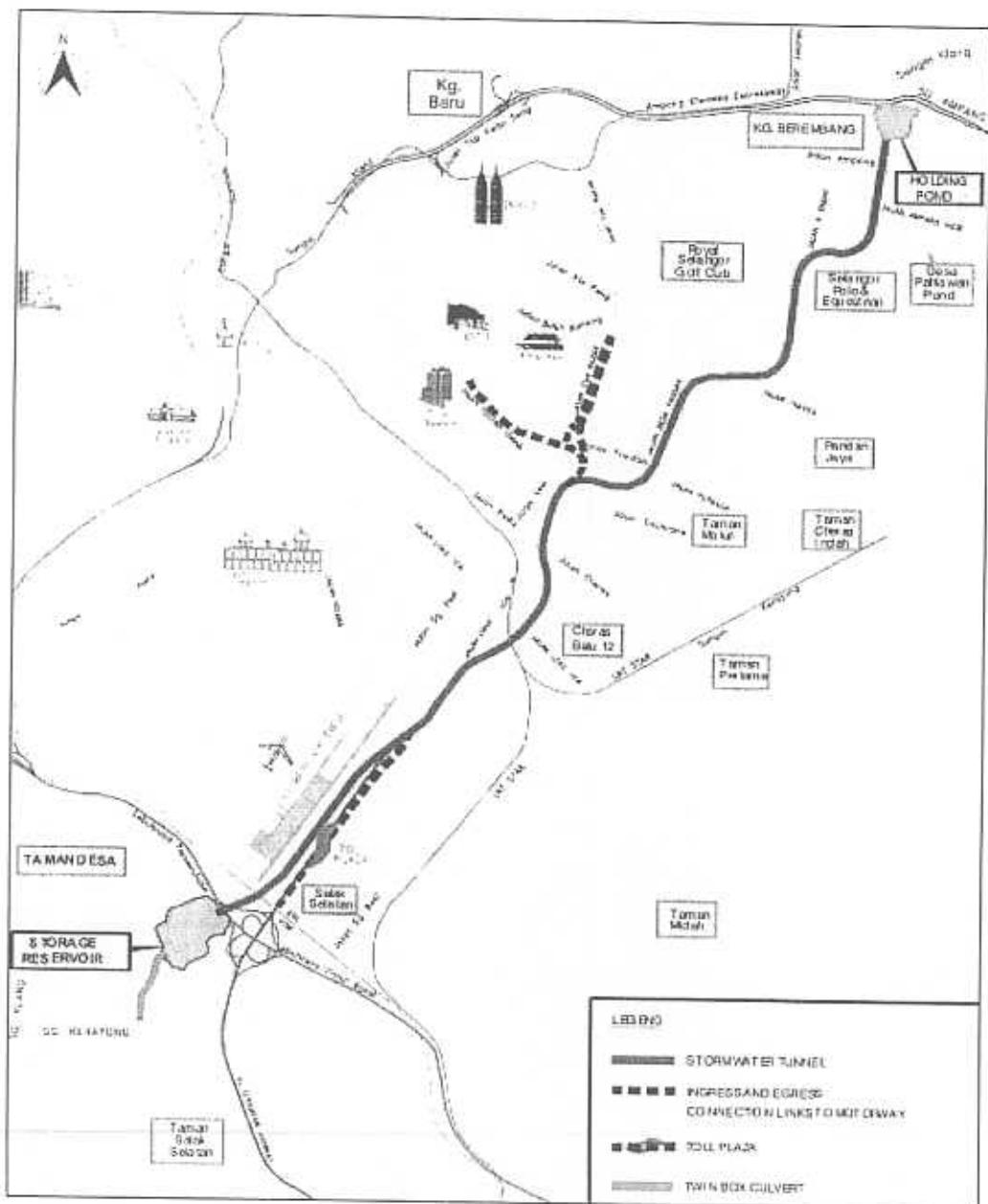


Figure 8. Project Location Plan Stormwater Management and Road Tunnel

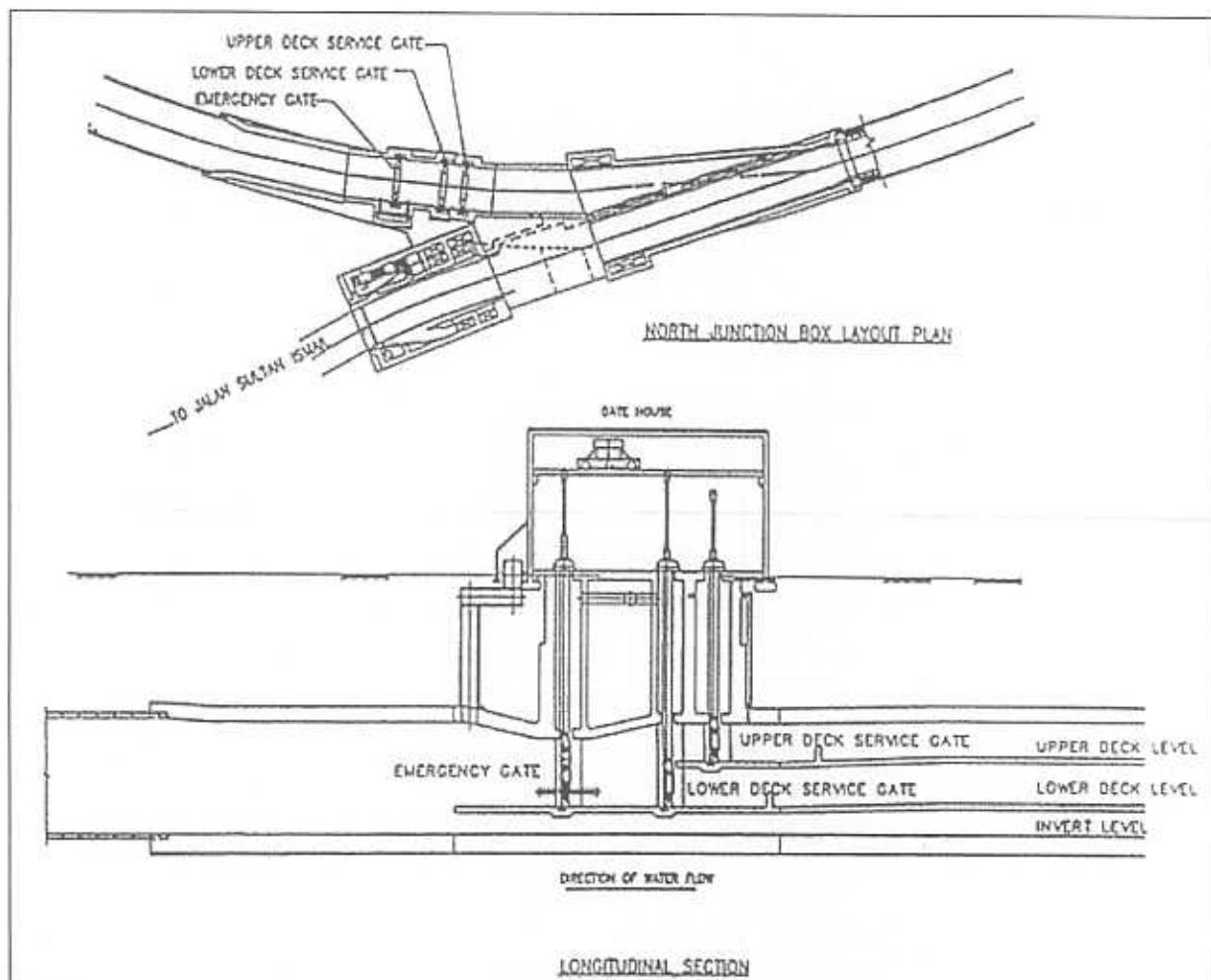


Figure 10. Upstream Stromwater Tunnel Flood Gates

## (2) The Traffic Tunnel

A double deck is chosen for the traffic compartment for safety reasons. It allowed one directional movement of traffic in the tunnel. The lower deck is designed for city bound traffic and the upper deck for traffic leaving the city. Due to limitation of headroom in the double deck configuration, only cars and other such light vehicles is allowed use of the tunnel.

Only two points of entry and exits are provided for vehicles using the tunnel, namely at the Kampong Pandan roundabout and at the KL/Seremban Expressway alongside the Sungai Besi RMAF runway. At both these locations elaborate ingress and egress systems has been designed to facilitate smooth flow of surface and tunnel traffic.

For ventilation, four shafts about equally spaced are provided in the 3 km length of the traffic tunnel. At these shafts specially designed ventilation system

comprising supply and exhaust fans are installed. They will be operated to ventilate each road deck and ensure air quality is safe, visibility is good, and smoke extraction in the event of a fire is possible.

Each shaft also functions as an escape access to the surface. They would be used for rapid deployment of surface help to either traffic deck in the event of an emergency. In between and at approximately 250-meter intervals escape passages are provided to connect the upper and lower road decks. Evacuation of people from one deck to the other is possible from these points when only one floor is experiencing an emergency.

Installations inside the traffic compartment will be designed to IP68 standard able to withstand water head pressure up to 25 meters and sustained flow velocity of 5 meter per second maintained for 24 hours. Protruding internal fixtures will be kept in streamlined housing to minimize resistance to water flow. Additionally ceramic epoxy paint will be used on the interior walls of the traffic tunnel to keep the surface impervious and smooth. This treatment helps in the

cleaning up operations after diversion and hastens the resumption of traffic after the flood flow.

### (3) Tunnel Exit Structure

This structure is located at the downstream end of the water Tunnel and is sited just south of the Federal Highway on the northeast end of Desa Pond.

It controls the release of water from the tunnel to the Storage Pond (i.e. the Desa Pond). The twin-gated structure comprises (Figure 11):

- i. an upstream chamber that connects it to the tunnel,
- ii. a downstream chamber, divided into two compartments, for housing the dewatering pumps and the gates, and
- iii. the discharge apron connecting the structure to the Desa Pond.

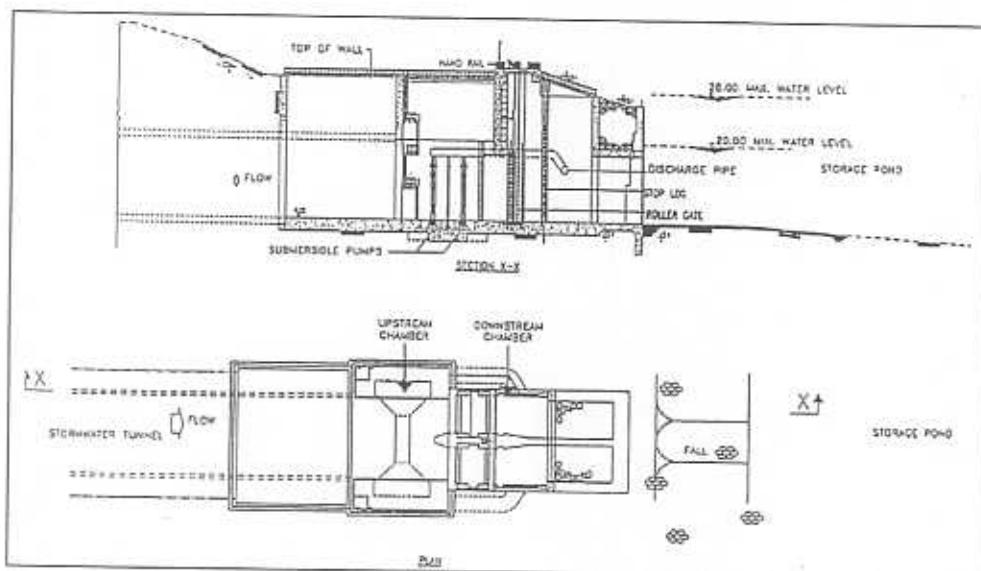


Figure 11. Outfall structure at the storage reservoir

The two gates provided in the structure to control water release are vertical roller type bulkhead gates 5.5m wide and 10.0m tall. When SMART is not activated for diversion, these gates are kept closed. This measure is necessary as otherwise there would be backflow of water from Desa Pond into the tunnel (tunnel invert 8.22mLSD, Desa Pond normal water level 20.00mLSD). When SMART is activated for diversion, the gates are opened. This enables the incoming stormwater to be released for storage in the Desa Pond. Should on such occasion, a gate or both fail to open, water will build up in the tunnel exit structure until it reaches a certain height and then discharge into the pond through outlet weirs specially provided for such an emergency.

In addition to the gates, the tunnel outlet structure is also fitted with pumps. These pumps, comprising four main submersible pumps and one smaller supplementary pump will be used to dewater the tunnel during the post-diversion period. The pumps are in-

stalled in specially prepared 1.3m deep sumps in the floor of the downstream chamber. Dewatering using the pump is only required towards the end of the dewatering process i.e. when the level at Desa Pond has receded to about 24.00m LSD from its maximum of 28.0mLSD. During the earlier phase, the tunnel deters by gravity.

The bed of the Desa Pond at the outlet of the tunnel exit structure is protected from scour by rock armor for a distance of 30m.

#### Storage & Release System

This is the part of the system that provides temporary storage for the flood waters and thereafter conveys it to the Kerayong River for release. There are two components to the system, namely (Figure 12):

- i. the storage reservoir
- ii. the release conduit to Kerayong.

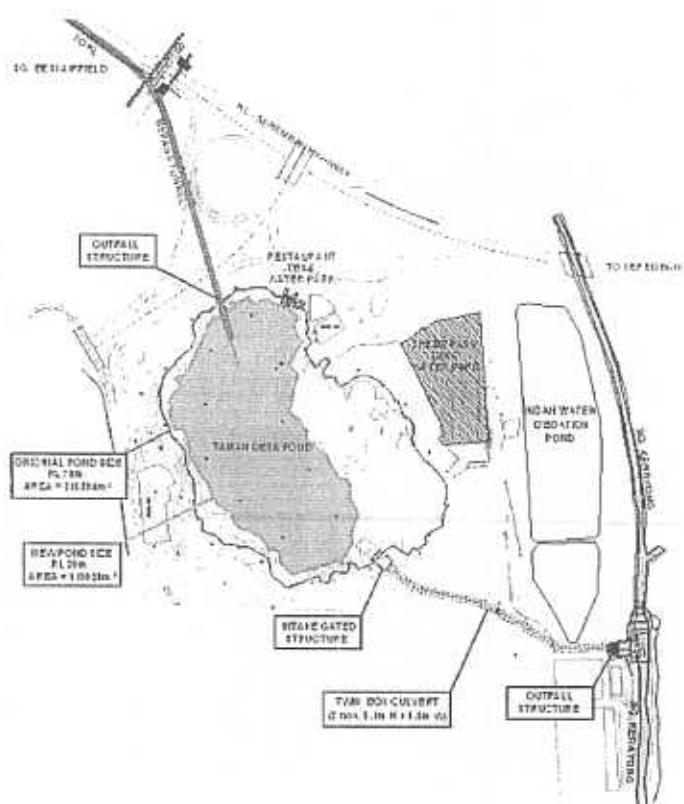


Figure 12. Storage Reservoir

### (1) The Storage Reservoir

This reservoir is a 22 ha abandoned ex-mining pond situated at the downstream end of the tunnel, just south of the Federal Highway. The present water level in the pond is 28.00mLSD. It would be lowered to 20.00mLSD for the operation of SMART.

The lowering is necessary:

- i. to achieve the gradient necessary for gravity flow in the tunnel
- ii. to create an additional 1.4 million cubic meters of storage in SMART for flood attenuation

### (2) The Release Conduit to Kerayong

This is a twin 5.0mx5.5m culvert connecting the storage reservoir to the Kerayong River. The culvert gated at both ends is approximately 500-meter long with its upstream and downstream inverts built respectively to 20.00mLSD and 19.50mLSD. The upstream gate is a service gate to separate the conduit from the storage pond. The downstream gate is a control gate used to regulate the release of water into the Kerayong River. Vents for air escape are provided in the release conduit. These are located downstream of the service gate, at mid point of the conduit between the pond and the river and upstream of the control gates (Figure 13).

The gates at the head of the release conduit is housed in a relatively simple structure, designed to accommodate the two 5.50m wide and 4.00m tall vertical roller service gates complete with their hoist mechanisms.

The downstream pair of control gates are housed in a more complex structure based on hydraulic design with a glacis and USBR Type IV stilling basin incorporated for energy dissipation. The control gates are also vertical roller type gates and to minimize on their cost, the internal height of the twin culvert is reduced from 5m to 3.5m just upstream of the outfall. The size of the control gates are therefore 5m wide and 3.5m tall. The invert at gate location is 19.50mLSD and the invert of the stilling basin floor is 16.80mLSD (cf riverbed at discharge end 18.10mLSD).

The control gate and the service gates are normally kept closed. When SMART is activated for diversion, the service gate will be opened and the twin culverts allowed to gradually fill as water enters the storage pond. During this operation, the flow in the Kerayong is monitored (Table 5). If observed to be below 300cumec, the control gates are operated to release water into the river. The control gates will be operated to regulate the release and ensure the flow in the Kerayong River does not exceed the design value.

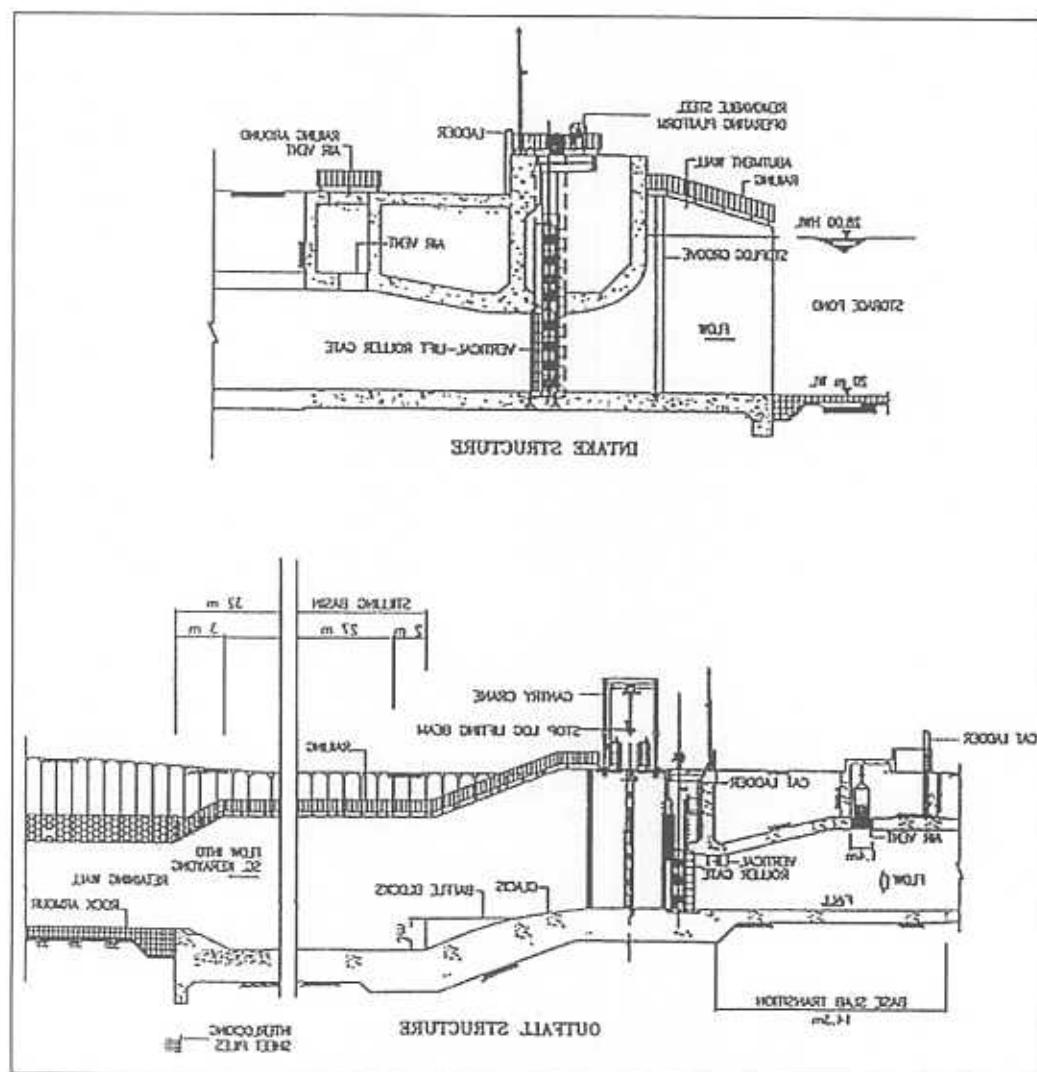


Figure 13. Twin box culvert n outlet structure

Table 5. Rating Curve, Kerayong River at SMART Outfall

Discharge in Kerayong (cumec)	Kerayong Water Level at SMART Outfall (mLSD)
50	20.3
100	21.7
150	22.4
200	23.0
250	23.6
300	24.2

Different types of flow would occur in the twin culverts depending on the rate of release. For low releases, the culvert would be part full and open flow conditions will prevail. As the release increases, the culvert will switch to pressurized flow. The head losses in the twin culvert system was computed using the method set out in USBR "Design of Small Dams" and the results are given in Table 6.

Table 6. Twin Culvert Headloss, Discharge = 200 cumecs

Entry Loss	0.472m
Friction Loss	0.975m
Bend Losses	0.027m
Contraction Loss	0.070m
Total Losses	1.544m

Under normal operation conditions, the level of water at the storage reservoir will be maintained at RL20.00m. When SMART is activated for storm discharge, water from the tunnel will be stored in the reservoir up to elevation RL28.00m and the situation at the Kerayong River watched. Upon conditions becoming favorable, the gates in the release conduit are opened for water to flow into the river. The release rate is however, regulated and not more than 200 cumec would be discharged into the Kerayong River.

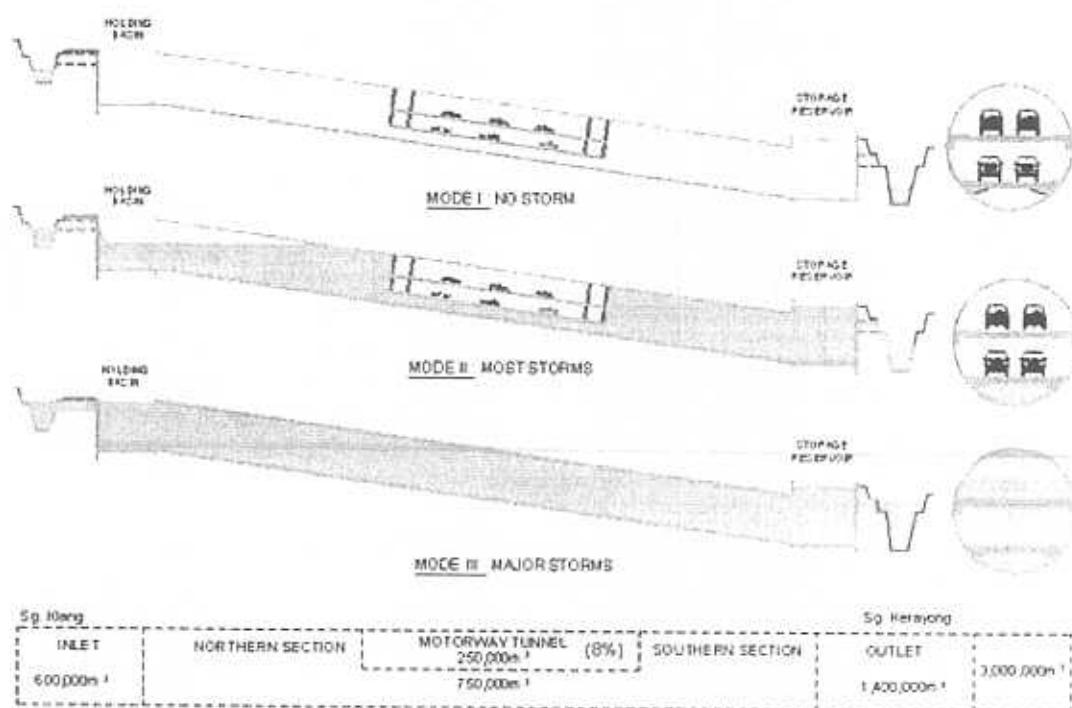


Figure 14. Summary of operational mode.

For this purpose, the affected length of the Kerayong River for this discharge would be suitably upgraded under the project.

The surrounding property in the vicinity of the storage reservoir has been investigated for adverse impact from the storage reservoir's operation and all necessary actions against land settlement and for slope stabilization requirements are covered in the implementation of SMART.

#### *Project Operation*

There are three modes in the operation of the SMART tunnel (Figure 14).

In mode I, which is the normal condition, the tunnel is 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 its other sections.

In mode II, some water is diverted into the tunnel but it would be confined to lowest drainage chamber provided in the traffic tunnel. During such times also, the set of twin floodgates at either end of the traffic tunnel is kept shut, to keep safe traffic in the tunnel. Each gate in the twin set is by design capable of seal-

ing the traffic compartment. Nevertheless, for safety reasons, a twin set is provided for backup.

In mode III, 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 is closed for traffic and secured for flooding. Road gates placed at either end of the traffic compartment will prevent water in the tunnel from reaching the surface at the ingress/egress.

Mode I will be the normal situation in most days of the year. Mode II is expected perhaps eight to ten times each year. Mode III may happen 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 at the most is required to dewater the system for cleanup. The cleanup and checks would take about 3 days before traffic resumption in the tunnel. Notwithstanding this, the component for stormwater management is designed to be ready in 24 hrs for handling the next storm.

#### *SMART Impact on City Flooding*

The objective of the flood mitigation strategy is to cut storm flows into the city down to manageable size.

As to what is manageable, a hydraulic study was carried out. It established the following conditions as necessary:

- i. peak at Tun Perak Bridge not greater than 180 cumec
- ii. peak from Bunus sub basin not to exceed 45 cumec
- iii. peak from Batu/Gombak sub basin not to exceed 400 cumec

In conjunction with SMART therefore two other Projects are also being implemented (Plate 18).

The first involves the construction of flood detention works by the City Hall to regulate the Bunus River. When completed the operation of these facilities would regulate the Bunus down to 45 cumec.

The second involves a project of the Department of Irrigation and Drainage, Malaysia in the Batu/Gombak sub basin. Under this project, several flood detention facilities using abandoned mining ponds would be constructed. The collective operation of these works when completed will keep the Batu/Gombak flow into Klang from exceeding 400 cumec.

SMART's operation is described below. There are three modes in the operation of SMART (Table 7).

Table 7. Operational Modes in SMART

Peak flood discharge from catchment above SMART intake	Mode
Up to 70 cumec	Mode I
Between 70 and 150 cumec	Mode II
Above 150 cumec to 290 cumec	Mode III

Under conditions of mode I, all the river flow is allowed into the city (Plate 17). When mode II is reached only 50 cumec is allowed into the city, the balance being diverted into SMART (Plate 17). Should conditions reach mode III the SMART will throttle the flow into the city down to 10 cumec (Plate 17). In all three situations SMART prevents the peak at Tun Perak Bridge from exceeding 180 cumec.

#### Flood Detection Measures

The safety of traffic in the tunnel is ensured by operation of a flood detection system that would give advance warning and sufficient notice for change in modes. A sophisticated SCADA aided control centre will be commissioned and operated by a skilled task force. Amongst the activity that would be carried out: comprehensive tracking of rainfall in the catch-

ment using ground instruments and radar generated imagery.

- i. continuous river stage and discharge measurements at key locations in the river system
- ii. real time transmission of above field data to control center
- iii. real-time flood hydrograph generations and peak predictions using field data received
- iv. gate operations using remote switching links
- v. CCTV monitoring at key locations.

All field stations will be live all year round, for continuous monitoring of weather conditions. When a storm is recorded in any part of the catchment, the network will immediately engage into detailed observation and analysis mode. Following an hour's observation of the storm the system will establish the mode for control centre follow up.

A set of actions for Mode II and Mode III will be drafted. These will be published as guidelines to the operators. If Mode II were predicted, guidelines would be followed for the tunnel to take in water. Traffic however is not affected. CCTV's would monitor conditions in the traffic tunnel. In the event of a mode III prediction, the tunnel would be secured, as in the guideline, for flooding. When this has been successfully completed, water is allowed into the traffic compartment.

#### SMART – Implementation

##### Component Parties

SMART is a project of the Government of Malaysia. The Department of Irrigation and Drainage, Malaysia and the Highway Authority of Malaysia are jointly appointed to oversee and coordinate the project on behalf of the government. Both departments carry out this responsibility in close association with several other government agencies.

The stormwater management component in the project is undertaken as a 'design and build' contract and is handled by a joint venture association of two leading construction companies in Malaysia, namely Malaysian Mining Corporation Bhd and Gamuda Bhd. The same joint venture association is also undertaking the road tunnel component of the project under a 'build, operate, and transfer' arrangement with Government. The principal consultant for the project is Sepakat Setia Perunding Sdn Bhd in association with Mott MacDonald (Malaysia) Sdn Bhd. Both companies have long records of accomplishment in providing engineering consultancy service in a variety of engineering disciplines.

### Project Schedule

SMART received the green light to begin construction activities in 2003. All works leading to the commissioning of the traffic tunnel will be completed by December 2005. Thereafter the remaining works will take another year to finish and by December 2006, therefore SMART is expected to be fully completed and operational.

### Choice of Tunnel Excavation Method

Given the rather tight project schedule, a lot of thought went into deciding the type of construction procedure to adopt. It had to be effective, speedy, and most important of all safe, considering the tunneling is through bedrock of limestone in an area that is heavily built-up.

Three choices were open for the tunnel excavation method, namely:

- i. 'cut & cover',
- ii. 'NATM' or
- iii. 'TBM'.

The 'cut & cover' method, as the name indicates is simply excavate, construct and backfill. There are some variations to this procedure; it can for instance be executed from 'bottom up' or alternatively 'top down'. Both processes are quite slow and during construction, a temporary roof over the pit is often a necessity to allow surface activities to carry on unimpeded. On the positive side though, 'cut & cover' allows for a wide selection of tunnel sections to be built. This technique is generally good for shallow tunneling or if short lengths are involved. Its application for lengthily tunneling through uncertain soil media is something that one should be cautious about.

In the 'NATM' or 'New Austrian Tunneling Method', the tunnel media in front is drilled, charges placed, and detonated. When using this method it is important that the structure of soil to tunnel is completely understood. In non-homogeneous material or cavity-filled rock, the 'drill and blast' technique may not be the good choice.

The third and more commonly adopted technique especially for long tunnel is to use the 'TBM' or the 'Tunnel Boring Machine'. There are generally three types of TBM to pick from:

- i. the open face machine for rock boring
- ii. the earth pressure balance (EPB) machine generally used for boring in loose soil

- iii. the mixshield (or slurry shield) TBM for media comprising hard material interfaced with loose soil

To decide on the choice of tunnel excavation method, a soil study was carried out based on extensive bore-hole sampling over the full length of the tunnel corridor. From the study, the soil profile along the tunnel alignment was produced (Plate 19).

As can be seen, the tunnel is founded on bedrock of limestone with varying depths of loose alluvium soils on top. This is quite typical of the ground structure in KL. Deep excavation and underground works in such areas need extreme care. The limestone profile is highly irregular. Moreover, rather than being solid, it is filled with cavities; exposing them during excavation would drain the cavities and cause a rapid drawdown of the water table. Soil is then drawn into the cavities and sinkholes appear on the surface.

The nature of soil structure led to the choice of the mixshield TBM for the tunneling. This TBM uses a slurry shield to ensure water tightness in front of the tunnel cutting face. The watertight front would then prevent the inflow of groundwater into the bored section should a cavity be exposed during tunneling.

Two TBM's have been purchased to be deployed on SMART (Table 8). Both will be launched from the north vent shaft. The first will bore towards the holding pond and the second towards the storage reservoir.

Table 8. TBM Specifications

Description		Specification
TBM	Type	mixshield
	Length of tunneling machine	71m
	Weight of tunneling machine	2,500 tons
	Installed power	8200kVA
	Cutterhead diameter	13,260mm
	Type	for hard rock & soft
	Segment outer diameter	12,830mm
	Advance speed nominal	0-2.5 cm/min

### Progress to Date

Since commencement of construction activities, the works undertaken to date involve the construction of the surface structures such as the diversion weir, the holding pond, the twin box culvert between the storage reservoir and the Kerayong River, the shaft junction boxes and the egress/ingress system for the road tunnel works. One TBM has begun boring in June 2004. This will be followed a few months later by the commissioning of the second machine. The overall progress, today is reported to be 30% and on schedule.

## CONCLUSION

Kuala Lumpur is a very important city. It is the nation's nerve centre for commerce and business. Large corporations have set up bases here. To serve them a growing number of local and foreign people keep flocking to the city. The city life is constantly in a state of transformation. As city dwellers become more and more affluent, their expectations keep rising.

This creates a demand that draws in the developers to provide more and more office spaces, shopping centers, housing, and entertainment facilities. KL is constantly being re-engineered. Development activities, particularly after the eighties have been intense.

In the face of these constant changes, existing infrastructures regularly come up being short. Without periodic upgrading, they become ineffective. This applied to the city's infrastructure for flood management. Development rendered the main drainage severely undersized to deal with present day levels of flood discharges.

To provide relieve, Government implemented the Klang River Basin Flood Mitigation Project. The project is in an advance stage of implementation. A midcourse review of it showed up a need for some additional measures. This led to the formulation of SMART.

The objective of SMART is to reduce the floodwaters entering the city. This is achieved by means of a diversion tunnel. The water diverted is then released into the river downstream of the city. Downstream flooding is prevented by regulating the release.

A tunnel has been chosen for the diversion conduit. Its use for flood management is not full time. Most days during the year, the tunnel would be dry. Part of the tunnel has therefore been designed for traffic. The dual use of the tunnel helps the project to be more cost effective.

A mixshield TBM has been selected for excavating the tunnel. It is the most sophisticated form of TBM in the market. This selection was considered necessary to undertake boring operations safely under the city. Adequate provisions are incorporated in the design to make the dual operation of the tunnel safe.

SMART is a Government project. The stormwater management is undertaken as a design and build contract. The road transport component is implemented as a build, operate and transfer project.

Construction, which began 2003, is scheduled for completion by December 2006. Works to open the tunnel for traffic will be completed by December 2005. The progress of works to date is reported as being on schedule.

## REFERENCES

SMART Appendices to Concession Agreement	2004
SMART Hydraulics Design Reports - SSP Sdn Bhd	2003
SMART Tunnel Filling Hydraulics & Surge Analysis - Mott MacDonald UK	Dec 2003
SMART Hydraulic Model Studies Final Report - Shuy Eng Ban & Chui Peng Cheong	Apr 2003

## BOOKMARKS

construction	parameter	name	value	test
	finish road	constfr	Dec 2005	Dec 2005
	finish storm-water	conststs	Dec 2006	Dec 2006
	start all	constsa	2003	2003

holding pond	parameter	name	value	test
	Total area	hpondta	9.4	9.4
	Diversion weir	dweirstill	type I	type I

tunnel	parameter	name	value	test
	Total length	tunneltl	9.8	9.8
	Road length	tunnelrl	3	3
	Escape spacing	tunneles	250	250
	Invert d/s	tunnelids	8.22	8.22
	Invert u/s	tunnelius	21.55	21.55
	Waterproof std	tunnelwps	IP68	IP68
	Waterproof press	tunnelwpp	25-meter	