academicJournals

Vol. 5(7), pp. 410-417, July 2013
DOI 10.5897/IJWREE2013. 0390
ISSN 2141-6613 © 2013 Academic Journals
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Performance analysis of the storm water management and road tunnel – SMART in Kuala Lumpur

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Accepted 12 June, 2013

Storm water management and road tunnel (SMART) was built to direct water around a major meeting point of two major rivers located in a large urban area; in addition, it doubles up as a road tunnel, though that section is only used in major storms. Much information has come from the Malaysian Department of Irrigation and Drainage (DID), in the form of data and reports. Pre-project historical water flow data as well as a simple velocity-area calculation to find the tunnel capacity was used to assess its efficiency. Water level data from the DID was used to create a graph in order to calculate the minimum amount of water to create flooding. Processing this information has revealed that SMART is in itself an effective flood deterrent, due to its water capacity and the lag time it creates. Although most storms should be easily dealt with, SMART only diverts water around the critical meeting point from one of the contributing rivers. It has no effect on the flow from the other river but it caused the sustained water to flow out. For an example, rainfall from a 100 year average return interval from this river will flood Kuala Lumpur. Although the development of SMART has been considered as successful, however, the growing development in the other part of the city could not ensure no flooding will take place or thoroughly protect the city centre.

Key words: Discharge, confluence, rainfall, storm water, drainage, frequency.

INTRODUCTION

During the monsoon season, every year the city of Kuala Lumpur experiences massive rainfall. Often this results in flooding around the central area of the city, resulting in massive losses to the economy and disruption to the lives of thousands. To prevent this again from occurring, the Malaysian Government financed the construction of the Storm water Management and Road Tunnel (SMART) as part of a wider flood mitigation scheme in the Klang Valley. The city of Kuala Lumpur sits at the centre of the Klang Valley conurbation, located on the west coast of peninsular Malaysia. Around six million people live in the conurbation and it has a total GDP of 263 billion RM (Malaysian Office of Statistics, 2010) a significant proportion of the nation's total. As a result, the government of Malaysia has invested a significant sum of money protecting it from flooding. Kuala Lumpur, the city at the heart of the conurbation, located at the confluence of two main rivers, the Klang and the Gombak. The confluence of the two rivers almost directly coincides with the city centre. So during the rainy season, massive amounts of rainfall fall on catchment areas of both rivers at once and these two large flows of water meet at this location. Additionally, the area where they meet has been extensively developed, making the area largely impervious and creating significant surface runoff during storms. Much of the flooding problems began in 1971 (Asian Development Bank, 2007), when urban development first started to grow. As the city contains

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Table 1. Information regarding the discharge station (DID, 2012).

Station No.	Station Name	State	Year Start	Latitude	Longitude	Critical Stage (m)	Catchment Area (sq km)
3116	Sg.Klang di Jambatan Sulaiman	WP KL	07/05	03 08 20	101 41 50	29.5	468

many sites of particular historical and economic interest to both the city and Malaysia, the government has taken steps to control it in a flood mitigation scheme. This study will concentrate on the critical confluence (Table 1). Measuring the discharge here and the effect SMART has on it. In this report, the success of the tunnel will be assessed from flood protection value. The flow of the major rivers in the conurbation will be studied, presenting a wider view of flooding problem in the area. At the end of the report, a passage shall be produced using the numerical data presenting a personal opinion on whether SMART has been effective in fully preventing flooding, and if not, what additional or remedial steps can be taken. This will be done by computing historical discharge data at a point before flow enters SMART. The effect that SMART has on this flow can then be computed. This could be done by finding the net flow reaching one of Kuala Lumpur's most flood prone sites. Capacity of the river at this point can then tell us whether overflow of the channel and, therefore, flooding will occur. The model used for this article is somewhat crude. Furthermore, it assumes many worst case scenarios have been met, in addition to some commonly used, assumptions regarding channel flow for ease of calculation.

MATERIALS AND METHODS

Outline methodology

Past flow data from the gauging station at Jambatan Sulaiman will be statistically analysed in order to determine the flow at that point, as well as the magnitude of floods with various return periods. It can then be compared against the flow capacity of the tunnel. As no rating curve was available online or at the DID library, one shall be created to compare any discharge values to the critical stage at the confluence, at which point overflow occurs.

Historical data

A frequency analysis of the historical discharge data is started by ranking the data in descending order, one being the highest, this rank can be divided by the total number of observations to get a frequency of exceedance. In other words, this is the probability of the value of discharge being exceeded. Return period is found by dividing one by the frequency of exceedance to find out the value in days, which can then easily be converted to years. After using Microsoft Excel to calculate the return period for each value of discharge, the values can be plotted (Figure 1) and the trend line forecasted. This can then be used to relate values of discharge for several different average return interval ARI's (Table 2) flooding events. Limitations of the method depend largely on the size and reliability of the data pool. A sample of seven years of data is all that was available for the study. The validity of using data spanning this time-frame to model the fifty year plus life span of SMART must be doubted, especially given a lack of extreme rainfall events in the data available. A statistical program called 'CumFreq' has also been used (Figures 2 and 3), the program fits a number of distributions to the data to the find the strongest relationship between the data sets.

Storm water management and road tunnel (SMART) volumetric flow limit

SMART can divert storm water at a limited rate, given by multiplying its internal cross, section area by the velocity the water can travel. This velocity is limited by the friction value of the material of the tunnel lining as well as the slope of the tunnel. I will calculate the limiting flow for the initial third of the tunnel, before the road section, simplifying the calculation to a circular area.

Assumptions made for this calculation include a constant cross sectional area across the tunnel as well as an average speed due to using average slope and material roughness. The calculations are only directly valid for the first and final thirds of the tunnel as the central third contains the road deck, which may alter flow calculations considerably. When the water reaches the road deck flow will be reduced, limiting overall flow, though insufficient data is available for this calculation. Flow could also be limited by the structural strength of the tunnel, such as being able to withstand high stresses during partial flow.

$$A_{total} = \pi r^2 = \pi \times (11.83/2)^2 = 109.9 \text{ m}^2 \text{ (4.s.f)} \quad (1)$$

Velocity is given by Manning's equation:

$$V = \frac{1}{n} R^{(2/3)} S^{(1/2)} \quad (2)$$

where:
V = flow velocity
n = Manning's n (assumed as 0.013 for finished concrete, partial pipe)
R = hydraulic radius (0.5 r or 0.25 d for circular pipelines)
S = tunnel slope

$$V = \frac{1}{0.013} (0.25.\ 11.83)^{(2/3)} (1.374\times10^{-3})^{(1/2)}$$
$$= 0.5875 \text{ m/s}$$

Therefore, the maximum flow the tunnel can cope is can be calculated by multiplying velocity with area as shown below:

Maximum flow = 0.5875 x 109.9 = 64.57 m^3/s

Rating curve formation

A rating curve relates the flow in the river to the height of the water from the riverbed (the stage). There is no publicly available rating curve for the Jambatan Sulaiman gauging station. As a result one

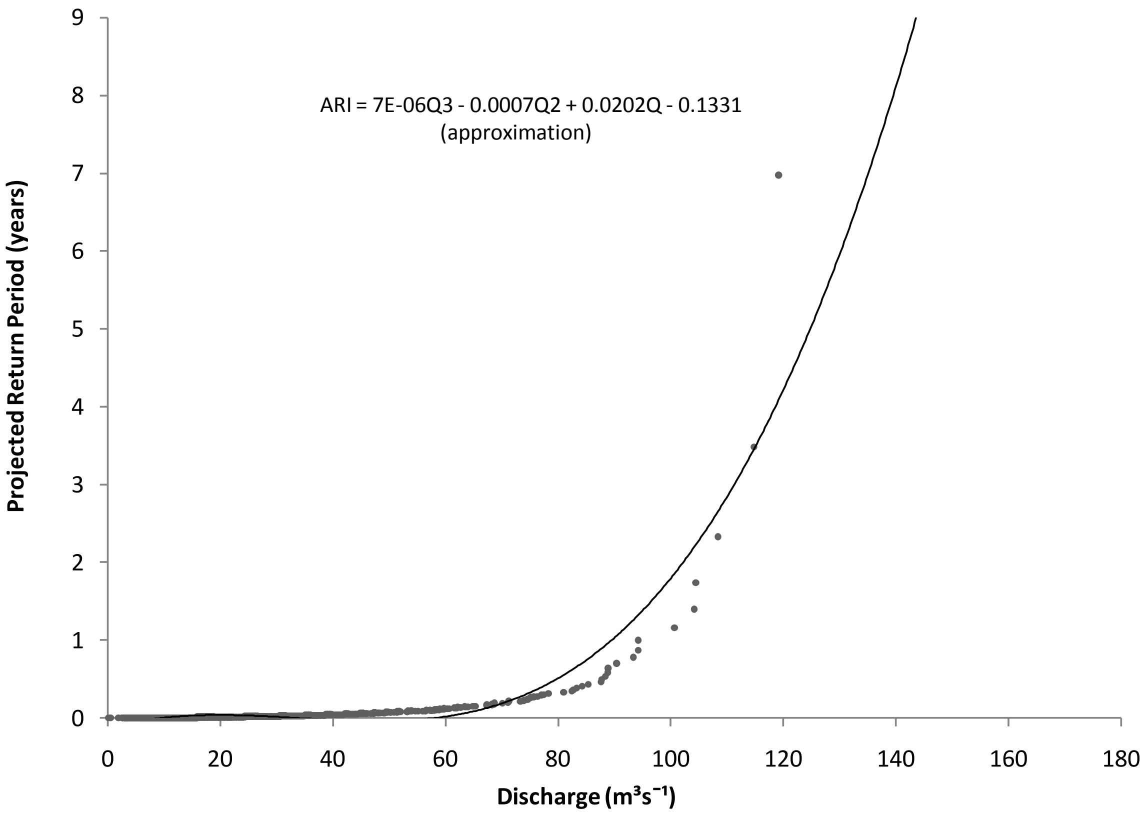

Figure 1. Return period plotted against discharge, including a trend line forecasted to predict up to 100 year ARI.

Table 2. Calculated discharge for various ARI values, taken from the trend line of Figure 1.

ARI year	Corresponding discharge m^3/s
2	101.23
5	124.27
10	147.20
20	176.23
50	226.67
100	276.57
6.97	134.58

was created in order to determine the flow which would result in the river overflowing at this location. To create the rating curve, data relating discharge to stage from a particular month was chosen with a wide range of discharge values. In this instance November 2001 was chosen, because full stage records were available online (DID, 2011). The discharge values are diurnal whilst the stage values available hourly, as a result there is ambiguity about which stage values to pick. In order to remain as consistent as possible, this paper has chosen the greatest stage value from each day; nonetheless the rating curve is less accurate because of this. Once the values are chosen they can be plotted and a trend line fitted. From this line, the critical discharge for overflow can be taken using the critical stage of 29.5 m (DID, 2012) by using the trend line equation. The validity of the equation will lack accuracy as no flow data is available around that depth. Once the graph was formed, the value for stage can be input from DID give the value of flow through the flow station above, which, channel overflow occurs. The critical value of flow found was then used to find the effectiveness of SMART in keeping the flow below this value.

RESULTS

The results seemed to create a strongly correlated curve as seen in Figure 1. Initially a third order polynomial is used to fit the trend line. Due to the insufficiency of data collected fitting 100 year ARI is bit difficult. The discharge for a 100 year storm is found using this curve and is found to be on the higher order. It is also understood that a greater range of data are needed to fit the proper curve and accurately. In actual, the frequency and level of information required has only been consistently recorded in Malaysia since the late 1990's (DID) and that has made the problem a bit difficult in getting accurate values. A table of results was recorded after finding the equation of the trend line from Figure 1. This is to show the discharge at Jambatan Sulaiman for various return period storms for ease of reference in the discussion in the Table 2 below. The rating curve is formed below using the basic linear relationship used in industry results seem to fit this approximation well with a reasonably strong

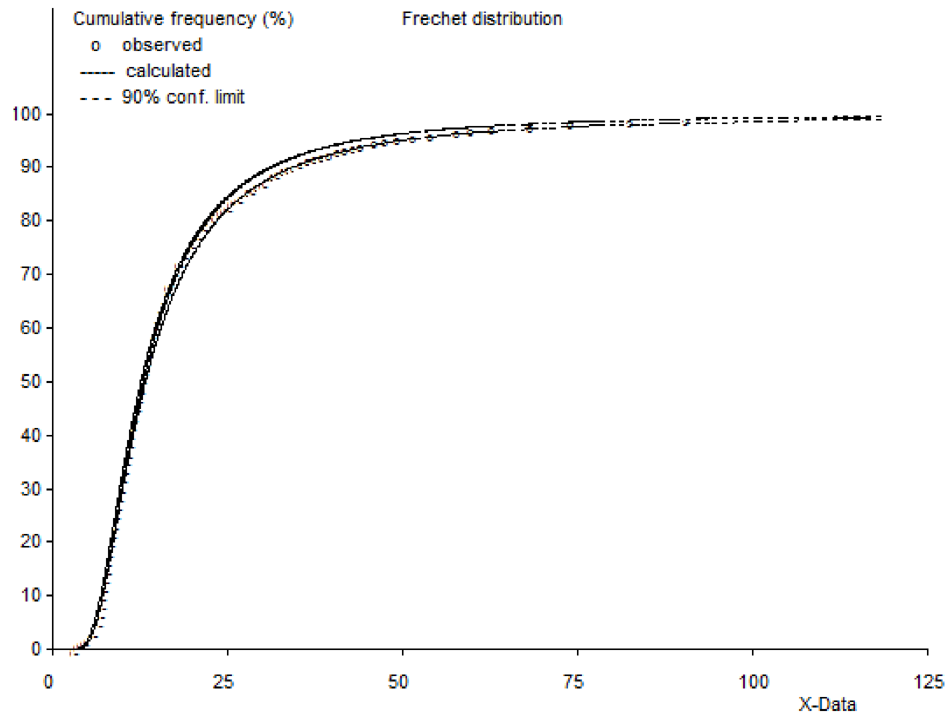

Figure 2. Cumulative frequency of ranked discharge data.

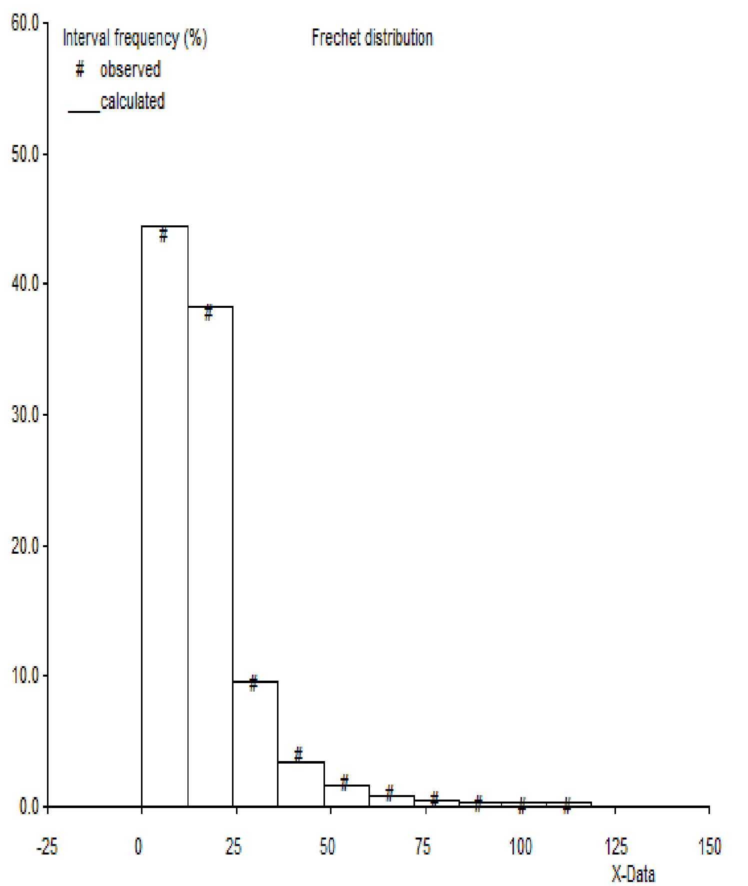

Figure 3. A frequency histogram of discharge results.

correlation. Rearranging the above equation and substituting 29.5 m for the stage value (S) gives a discharge of 188.3 m^3/s, the discharge above which the river overflows it banks.

DISCUSSION

Combining critical discharge of 188.3 m^3/s (found using Figure 4 and Table 1) and SMART's capacity of 64.6 m^3/s at the critical flooding point at Jambatan Sulaiman it can be concluded the confluence will not flood with a hypothetical discharge of 252.9 m^3/s from all upstream areas. For no flooding to occur at this discharge, at least 64.6 m^3/s of the water flow must be sourced from the Klang side of the confluence (neglecting the small quantity of water that is added to the river between SMART and the discharge station). Storage of the holding ponds also has an effect, so in reality it could be dealt with a larger quantity of water. In reality this is dependent on water levels in the holding ponds before storm onset. As seen in Figure 5 above SMART does nothing to prevent higher flow from the Gombak side of the confluence, excess flow from this side can still flood central Kuala Lumpur. If a 100 year ARI rainfall event were to occur across the Gombak and Klang catchments, SMART would not be able to cope on this basis (Table 1). In reality storage of holding basins and the Gombak Dam should be able to hold much water. Protection of the centre of Kuala Lumpur depends on prudent management of storm defence resources. SMART only solves the problem of flow from the Klang River, not the Gombak River, once high discharge is recorded along the Gombak, and only so much can be done to divert water from the Klang side of the confluence at the levels necessary to reduce flow at the confluence. This is especially true considering that traffic in the tunnel means immediate use of the tunnel is impossible.

The historical data show most of the measured flow is small, and SMART is rarely needed. Less than 15% of the flow is high enough to consider using tunnel. Because of the road decks, the central section is essentially split into three tunnels that can be operated independently using flood gates. Full use of the tunnel is only very rarely needed (Figure 3). However 100 year discharge is rare by its own definition. SMARTs main purpose is to prevent the smaller scale floods such as a 10 year ARI of 124.27 m^3/s. The tunnel can divert such flows very efficiently provided the rainfall is not widespread across the entire contributing catchment. If widespread rainfall did occur, or sustained rainfall had already saturated the catchment and filled the city's flood defences to capacity, the tunnel would not be able to prevent flooding. Its scope of use is limited and the tunnel cannot be considered a comprehensive flood defence. The flash floods in June 2007 seem to confirm this point, the floods having occurred post-project. Operation of the tunnel substantially depends on other Klang Valley mitigation project installation. Far upstream of the city the Klang Gates Dam has been fitted to store water and act as a flood defence. If the dam were to be near capacity due to extensive rainfall or mismanagement, the tunnel would receive a greater amount of water compare to any normal scenario. This event is highly possible given the nature of the statistical method used, as it is possible to receive two 100 year rainfall events within days of each other.

As with all but the most audacious flood projects, the problem has just been moved downstream to still developing area in terms of flood monitoring and management in the catchment. The value for the SMART lies in the lag time it creates to protect these areas. Due to the large combined storage of SMART and the holding ponds, the lag time is highly effective. In fact, the real value that the SMART contributes to the flood defence of the conurbation will be larger than above calculation. In the event of further urban development, where SMART rejoins the river system at Sungai Kerayong (Figure 4), more measures may need to be taken to mitigate floods. As local drainage adds more water to the river system the flow will become more likely to burst its banks downstream, this has occurred recently in the Jalan Brickfields areas. Realistically the flood capacity of the system has to be improved as more water is added from local drainage, something which has been neglected.

Combining critical discharge of 172.2 m^3s^{-1} and SMART's capacity of 64.57 m^3s^{-1} at the critical flooding point at Jambatan Sulaiman means the confluence will not flood with a (theoretical) discharge of 236.77 m^3s^{-1}, provided at least 64.57 m^3s^{-1} of the water flow is sourced from the Klang side of the confluence (Figure 6); neglecting water that is added to the river between SMART and the discharge station, which will be small. Storage of the holding ponds also has an effect, so in reality a larger figure could be dealt with.

Despite repeated attempts to counter flooding problems, they continue to occur, suggesting a flaw in the areas flood defences. The validity of methods to calculate the rainfall and flooding in Malaysia should be investigated. Many of the techniques used have merely been adapted from manuals of more temperate climate countries, which contrast greatly with the extreme (in rainfall terms) tropical climate of Malaysia. Creating smaller tunnels around the city, using cheaper existing tunnel boring machines, would have been a possibility, though further study would be needed to confirm this. Another solution would be to widen the current channels to maximise flow, as rivers are too narrow to deal with flow, due to extensive urban development on the river banks. Lack of vegetation around the city also contributes to a large runoff, effort needs to be made to incorporate more sustainable urban drainage solutions into the city.

Another factor of a road tunnel is that its maintenance and operation costs are large. A tunnel focused solely on flood prevention would not have anywhere near these

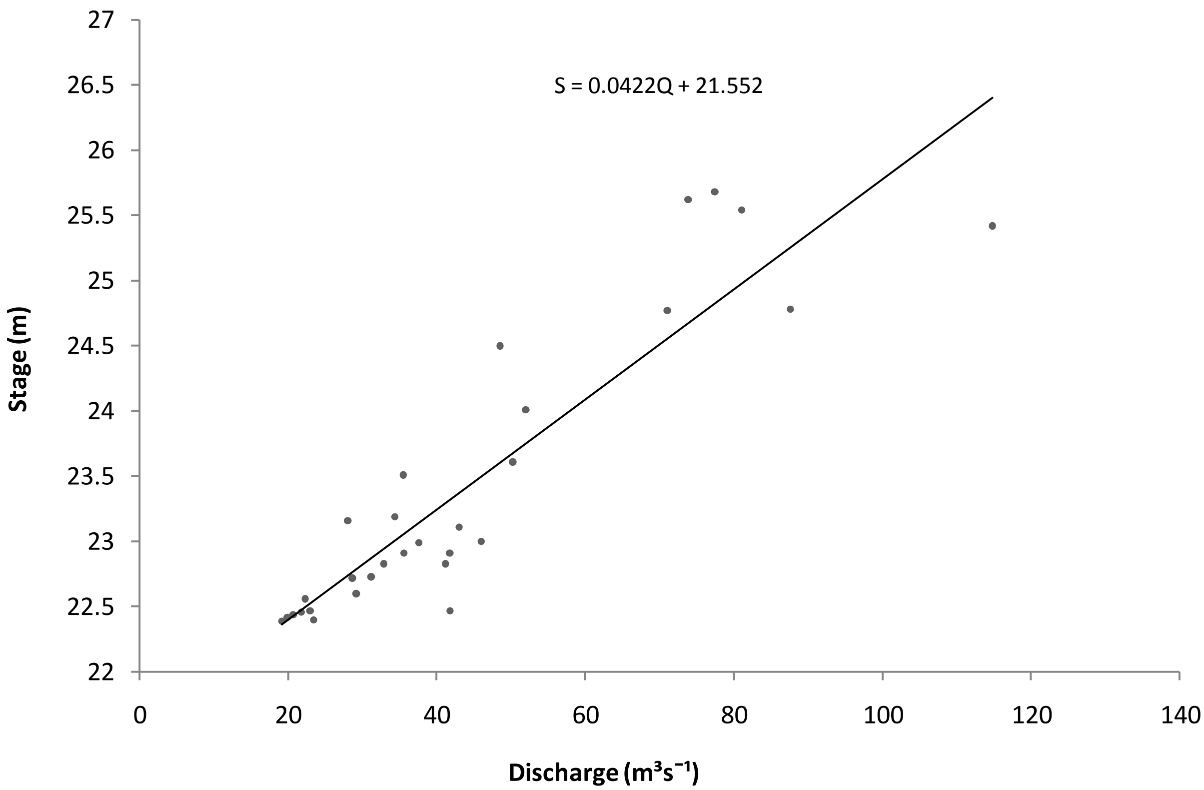

Figure 4. Rating Curve for Jambatan Sulaiman, River Klang.

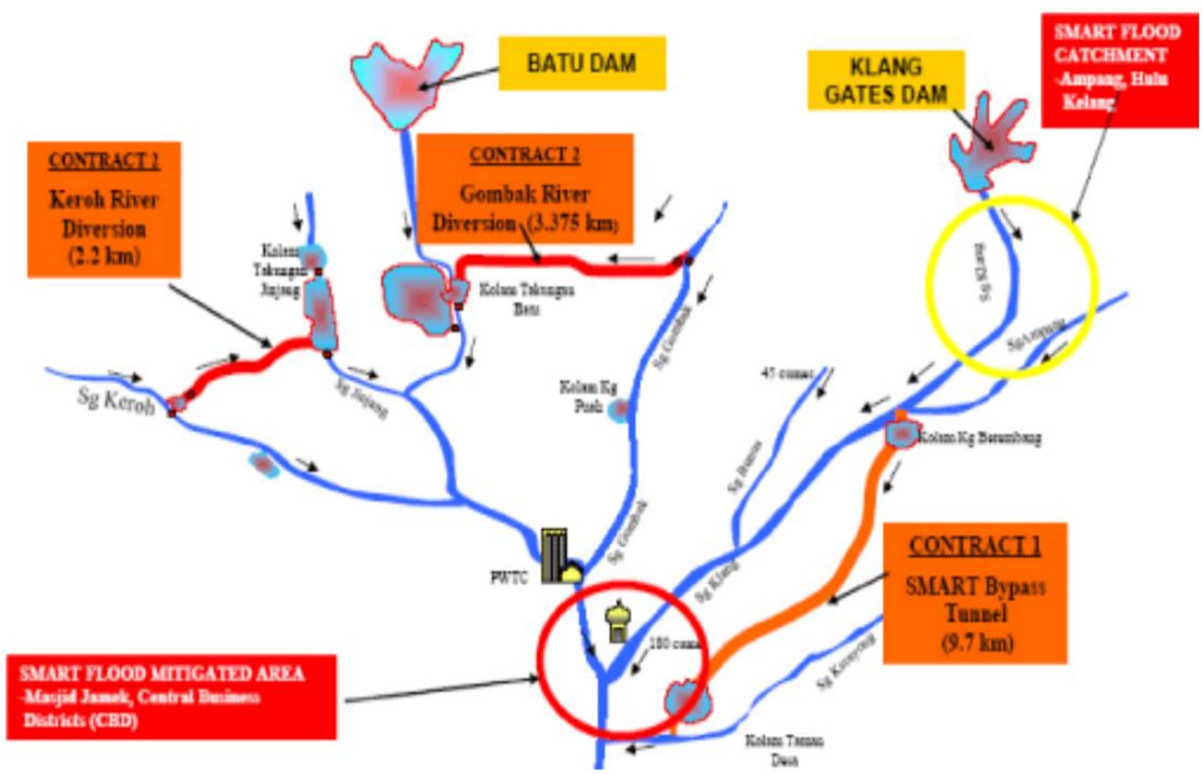

Figure 5. Map of the critical confluence and contributing catchments (SMART Motorway Tunnel, 2012).

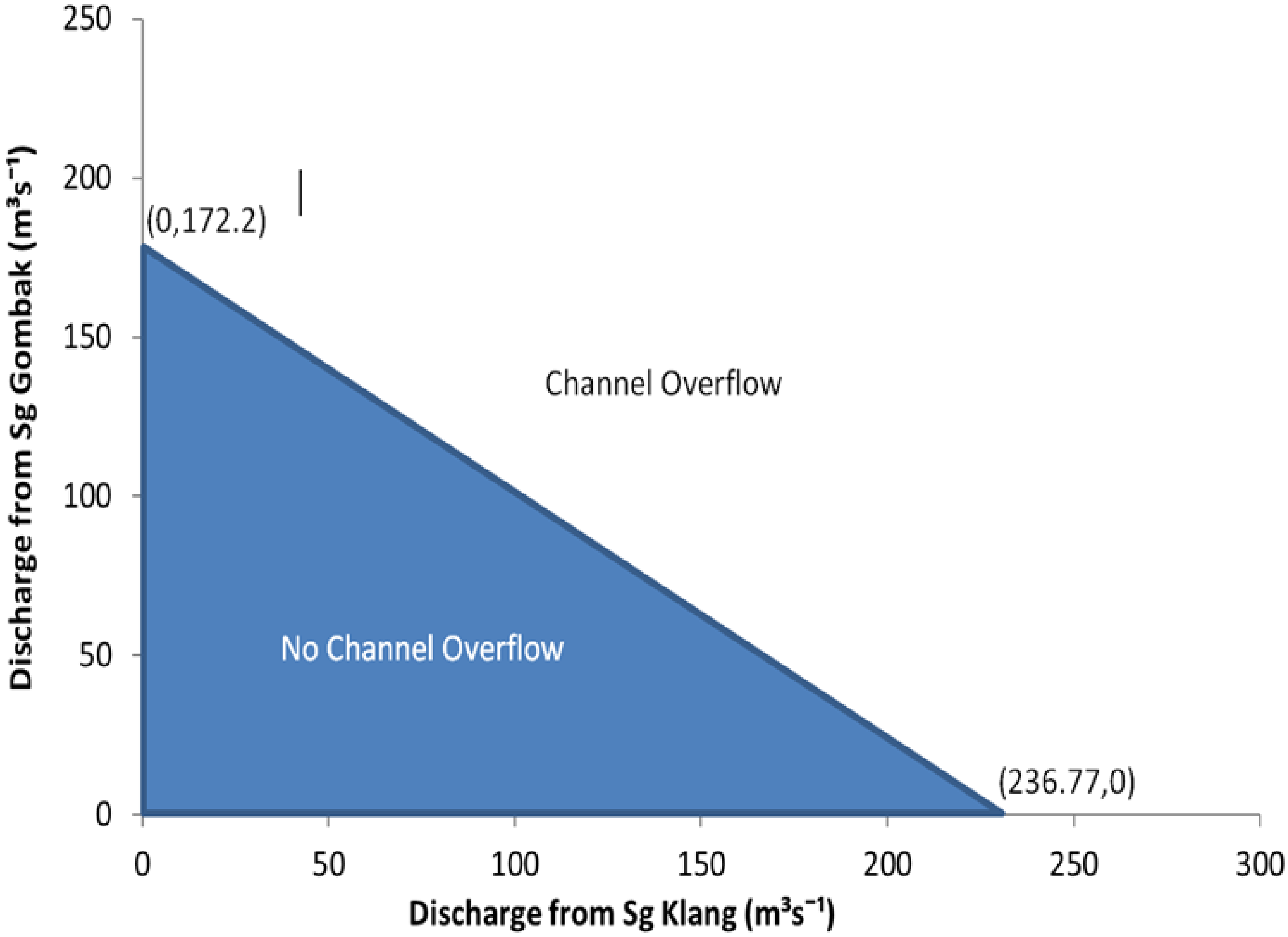

Figure 6. Graph to show combined discharge from the rivers at the confluence, weighted for each river using their respective catchment area.

costs, though revenue would also be affected. Though the tunnel is profitable at current traffic levels, wearing with age and improvement of public transport can only reduce this. A tunnel or channel designed exclusively for flooding may have worked out cheaper. A feasibility study would be needed to determine this. However, it is less debatable that for a city the size of Kuala Lumpur, a road tunnel of the scale of SMART is unsustainable when public transport can be improved.

Conclusion

There is no doubt that SMART is beneficial to the flood defence, it can successfully divert large quantities of water downstream of the city centre. The downstream areas of the city that receive the diverted storm water are less urbanised, and more land is available to widen the channel and contain any flooding. The main advantage of the tunnel in this respect is the lag time it creates with its storage capacity. In transport terms it serves as a useful alternative route for motorists to and from the city centre, living up to its reputation as an innovative solution to two of Kuala Lumpur's problems. However, a more detailed investigation and traffic survey would be needed to ascertain its value more thoroughly. Current figures suggest it saves Kuala Lumpur municipal council 13 to 151 million US dollars per year in social damages (United Nations, 2011). This is due to flooding in the city centre because of the floods it creates. Therefore from a pure socio-economic viewpoint it is a success.

However, this report aims to focus on its impact on flooding. As mentioned before it is a highly effective tool; however additions are needed to mitigate the Gombak side to ensure no flooding comes from its side of the confluence. In its current form, it is an imbalanced solution. Without the installation of extra flood defences on the opposite side of the city centre confluence, from the Gombak River, a rainfall event across the upper Klang catchment still has the potential to cause flooding. At this moment in time much money is wasted on SMART's higher capacity flood reduction value if these defences are not added or a more sustainable solution embraced. Additionally, due to the nature of statistical analysis, it is impossible to say when and how much exactly a 100 year flood could be. One particularly bad rainfall event could overload the flood mitigation system especially for the downstream side of the catchment. Most importantly though effective management is needed to ensure that SMART project is protecting Kuala Lumpur city centre from flooding, only a complete, well monitored and a holistic implementation of the project would survive longer with the unpredictable tropical rainfall.

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