# EFFECT OF DESIGN PEAK FLOW FACTOR TO THE CAPITAL COST OF SEWERAGE RETICULATION IN MALAYSIA

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# DEDICATION

*I dedicate this humble effort to my parents,*
*my beloved wife and our lovely son for their*
*continuous prayers, love, support and understanding*

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# ABSTRACT

The design peak flow factor (DPFF) formula prescribed in MS1228:1991 is commonly adopted in sewerage industry in Malaysia although the validity of this formula has not been verified since its publication 24 years ago. Local research findings and feedback from industry revealed that the DPFF has been over provided for all sewerage services which lead to over design and increase in capital cost as well as operation and maintenance (O&M) cost. The Government has planned to raise the sewerage tariff to cover high O&M cost in sewage treatment plants. In view of RM10.3 billion of sewerage projects had been approved under the Tenth Malaysia Plan, the research on design and cost optimization in sewerage services is timely and in line with country needs. The aim of this research is to prove via statistical analysis that the DPFF is higher than both the actual peak flow factor (APFF) in sewerage services and international peak flow factor (IPFF); to recommend a more optimised peak flow factor (PFF) formula in lieu of the current DPFF; and to evaluate its financial effect to the sewerage reticulation projects in Malaysia. Hourly flow data was collected via online electromagnetic and ultrasonic flow meter connected to the Supervisory, Control and Data Acquisition (SCADA) system at five centralised sewage treatment plants (CSTP) with capacity ranging from 73,000 to 394,000 population equivalent (PE). The analysis revealed that the DPFF for all five CSTPs were overprovided by 23% to 63% as compared to the APFF. A comparison between Malaysian DPFF with six IPFF formulas, namely Babbitt, Duncan, Gifft, Harmon, Johson and Utah showed that Malaysian DPFF is the highest among all IPFFs from 10,000 PE to 1 million PE. In addition, the APFF calculated for five CSTPs are close to Utah, Babbitt and Harmon PFF. Based on the highest APFF among five CSTPs, a more optimised PFF formula: $3.8/P^{0.11}$ (named as Lee's PFF) is recommended in lieu of the original DPFF of $4.7/P^{0.11}$. Three IPFF i.e. Utah, Babbitt and Harmon, together with Lee's PFF were selected for financial analysis which involve proper engineering design using Manning equation by Professional Engineers for five actual centralised sewerage reticulation projects of 72,000 PE to 554,000 PE. The financial analysis revealed that capital cost saving of up to 7.6% (RM35.5 million) and 5.1% (RM23.6 million) can be achieved from the total capital cost of RM464 million for five projects, using IPFF (Babbitt) and Lee's PFF, respectively. The above findings warrant a full scale review of the current DPFF formula prescribed in MS1228:1991 for the interest of the country.

# ABSTRAK

Formula factor aliran reka bentuk puncak (DPFF) yang diperkenalkan di dalam MS1228:1991 telah diterima pakai dalam industri pembetungan Malaysia sejak diwartakan 24 tahun yang lalu walaupun formula ini tidak pernah disahkan kesahihannya. Maklum balas daripada penyelidikan tempatan dan pakar industri menunjukkan peruntukan DPFF yang tinggi menyebabkan sistem pembetungan direka melebihi kapasiti yang diperlukan dan meningkatkan kos modal serta kos operasi dan penyelenggaraan (O&M). Kerajaan Malaysia telah bercadang untuk menaikkan tarif pembetungan untuk menampung kos O&M yang tinggi untuk loji rawatan kumbahan. Memandangkan RM10.3 bilion telah diluluskan untuk projek pembetungan di bawah Rancangan Malaysia Kesepuluh, penyelidikan untuk mengoptimumkan reka bentuk dan kos sistem pembetungan adalah tepat pada masanya dan sejajar dengan keperluan negara. Matlamat penyelidikan ini adalah untuk membuktikan melalui analisis statistik bahawa DPFF adalah lebih tinggi daripada factor aliran puncak sebenar (APFF) serta factor aliran puncak antarabangsa (IPFF); mencadangkan formula factor aliran puncak (PFF) yang lebih optimum bagi menggantikan formula DPFF yang sedia ada; serta menilai kesan kewangannya ke atas projek paip pembetungan di Malaysia. Data aliran air kumbahan setiap jam telah dikumpulkan melalui meter aliran atas talian jenis electromagnet dan ultrasonik yang disambungkan kepada sistem Penyeliaan, Kawalan dan Perolehan Data (SCADA) di lima loji rawatan kumbahan berpusat (CSTP) dengan julat kapasiti daripada 73,000 sehingga 394,000 kesetaraan populasi (PE). Hasil analisis menunjukkan DPFF untuk kelima-lima CSTP adalah 23% sehingga 63% lebih tinggi daripada APFF yang dihitung. Perbandingan antara DPFF Malaysia dengan enam formula IPFF, iaitu Babbitt, Duncan, Gifft, Harmon, Johnson dan Utah menunjukkan bahawa DPFF yang digunakan di Malaysia merupakan yang paling tinggi dari 10,000 PE sehingga 1 juta PE. Selain itu, keputusan analisis juga menunjukkan APFF kepada lima CSTP adalah berhampiran dengan formula Utah, Babbitt dan Harmon. Berdasarkan APFF yang paling tinggi di antara lima CSTP, formula PFF yang lebih optimum: $3.8/P^{0.11}$ (dinamakan sebagai Lee's PFF), dicadangkan untuk menggantikan formula DPFF yang asal iaitu $4.7/P^{0.11}$. Tiga formula IPFF, iaitu Babbitt, Harmon dan Utah bersama dengan Lee's PFF telah dipilih untuk analisis impak kos yang menglibatkan reka bentuk kejuruteraan menggunakan formula Manning oleh jurutera profesional untuk lima projek paip pembetungan berpusat sebenar daripada 72,000 PE sehingga 554,000 PE. Analisis impak kos menunjukkan bahawa penjimatan jumlah kos modal sebanyak 7.6% (bersamaan dengan RM35.5 juta) dan 5.1% (bersamaan dengan RM23.6 juta) boleh dicapai daripada lima projek paip pembetungan yang bernilai RM464 juta dengan masing-masing menggunakan IPFF (Babbitt) dan Lee's PFF. Justeru, penemuan di atas telah menunjukkan keperluan untuk mengkaji semula formula DPFF yang ditetapkan di MS1228:1991 untuk kebaikan negara.

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| | | |
|---|---|---|
| A | - | Flow Area |
| k | - | Peak Flow Factor |
| km | | Kilometer |
| l/s | - | liter/second |
| mm | - | Millimeter |
| m | - | Meter |
| $m^3$/day | - | Meter Cubed per Day |
| $m^3$/hr | - | Meter Cubed per Hour |
| m/s | - | Meter per Second |
| n | - | Manning's Roughness Coefficient |
| P | - | Estimated Population Equivalent (PE in thousands) |
| Q | - | Flow Rate |
| $Q_{peak\ hourly}$ | - | Peak Hourly Flow Rate |
| R | - | Hydraulic Radius |
| S | - | Channel Slope |
| v | - | Velocity |
| % | - | Percentage |
| Δ | - | Difference |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AMN | - | Ammoniacal Nitrogen |
| APF | - | Actual Peak Flow |
| APFF | - | Actual Peak Flow Factor |
| $BOD_5$ | - | Biochemical Oxygen Demand |
| BQ | - | Bill of Quantity |
| COD | - | Chemical Oxygen Demand |
| CST | - | Communal Septic Tanks |
| CSTP | - | Centralised Sewage Treatment Plant |
| DAF | - | Design Average Flow |
| DPF | - | Design Peak Flow |
| DO | - | Dissolved Oxygen |
| DPFF | - | Design Peak Flow Factor |
| EPU | - | Economic Planning Unit |
| HDPE | - | High Density Polyethylene Pipe |
| IL | - | Invert Level |
| IPFF | - | International Peak Flow Factor |
| IST | - | Individual Septic Tanks |
| IWK | - | Indah Water Konsortium |
| JPP | - | Jabatan Perkhidmatan Pembetungan |
| KeTTHA | - | Ministry of Energy, Green Technology and Water Malaysia |
| KL | - | Kuala Lumpur |
| KLCC | - | Kuala Lumpur Convention Center |
| KTM | - | Keretapi Tanah Melayu |
| LRT | - | Light Railway Transit |
| M&E | - | Mechanical & Electrical |

| | | |
|---|---|---|
| MLSS | - | Mix Liquor Suspended Solids |
| MOHE | - | Ministry of Higher Education |
| MSIG | - | Malaysian Sewerage Industry Guidelines |
| NPS | - | Network Pump Station |
| O&G | - | Oil & Grease |
| O&M | - | Operation and Maintenance |
| PE | - | Population Equivalent |
| PFF | - | Peak Flow Factor |
| PLC | - | Programmable Logic Controller |
| QS | - | Quantity Surveyors |
| RCP | - | Reinforced Concrete Pipe |
| RMK 9 | - | Ninth Malaysian Plan |
| RMK 10 | - | Tenth Malaysian Plan |
| RMK 11 | - | Eleventh Malaysian Plan |
| SCADA | - | Supervisory Control and Data Acquisition |
| SCCF | - | Sewerage Capital Contribution Fund |
| SCS | - | Sewerage Catchment Strategy |
| SPAN | - | Suruhanjaya Perkhidmatan Air Negara |
| SS | - | Suspended Solid |
| SSD | - | Sewerage Service Department |
| SSP | - | Sepakat Setia Perunding Sdn Bhd |
| STP | - | Sewage Treatment Plant |
| TN | - | Total Nitrogen |
| TP | - | Total Phosphorus |
| UK | - | United Kingdom |
| UTM | - | Universiti Teknologi Malaysia |
| VCP | - | Vitrified Clay Pipe |
| WTP | - | Wastewater Treatment Plant |
| WSIA | - | Water Services Industry Act |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

In the past century, the primary objective of sewerage services in Malaysia was for public health care, mainly focus on the control of waterborne diseases due to discharge of untreated sewage. In line with the Government's vision for Malaysia to become a developed nation by 2020, the sewerage objective has been upgraded towards the environmental protection; whereby more attention is given to the compliances of sewage treatment plant (STP) discharge to regulatory requirement, i.e. meeting more stringent effluent standard (SSD, 1999). This can be seen with the enactment of Environment Quality (Sewage) Regulation, 2009 (Malaysia, 2009) with more stringent treated effluent standard to substitute the Environment Quality Act 1974.

"Guidelines for Developers" published by Sewerage Services Department (SSD) in 1999 which was later revised as the "Malaysian Sewerage Industry Guideline" (MSIG) by the *Suruhanjaya Perkhidmatan Air Negara* (SPAN), in 2009 had been commonly adopted by the sewerage industry in Malaysia for the planning, design, authority submission, construction, handing over, operation, maintenance etc of sewerage services (SSD, 1999 & SPAN, 2009a & 2009b).

It was stated in SSD's guideline (1999) that the future direction of sewerage infrastructures shall be towards rationalisation of multi points STP into centralised sewerage treatment plants (CSTP). The continuation of this vision can be seen in the SSD's annual report 2011, whereby the following long term national sewerage plan was set up by SSD:

i. To increase coverage of sewerage network in urban catchment from 60% to 87% connected population equivalent (PE) by 2040.
ii. To decommission and rationalize small STP to be replaced by CSTP in order to increase PE coverage of centralized sewerage system from 19% in 2008 to 79% by 2040. It was stated that the number of CSTP was estimated to increase to 223 plants by 2040.
iii. Higher compliances to effluent standard.
iv. Promoting green technologies in sewerage industry.
v. To replace the existing sub-standard septic tanks (5 million units septic tanks were estimated in 2007) with better on site treatment system to meet effluent standard for the needs of semi urban or rural catchment

In line with the national sewerage plan, the Eleventh Malaysian Plan (RMK 11) for 2016-2020 published by the Prime Minister's Department of Malaysia, has reported that 3000 individual STPs was identified for rationalisation into centralised sewerage system in order to reduce the operation and maintenance (O&M) cost by approximately 50% (mainly for power consumption and labour cost) besides achieving higher treatability to produce better effluent quality. It was revealed that the annual O&M cost for 6000 multi points STPs in 2010 was in the range of RM1-3 million each, which is a financial burden to the country (EPU, 2015a & 2015b).

According to the annual reports published by SSD and Ministry of Energy, Green Technology and Water Malaysia (KeTTHA), the Government of Malaysia has allocated approximately RM4.5 billion (from 2006-2013) under the Ninth and Tenth Malaysia Plan (RMK 9 & RMK 10) from 2006 to 2015 to SSD for implementation of sewerage projects nationwide (SSD, 2011-2014 and KeTTHA, 2014). It was reported that the total 22 sewerage projects under Greater Kuala Lumpur/ Klang

Valley with total estimated project cost of RM5.6 billion had been approved in December 2010 to be implemented in stages (SSD, 2011). It was also revealed by the Economic Planning Unit (EPU) under the Prime Minister's Department of Malaysia that sewerage projects with total value of RM10.3 billion was approved under the RMK 10 to modernise sewerage infrastructure in Malaysia (EPU, 2015a).

Besides the allocation from the federal government, the sewerage projects are being implemented via developers funding and the funding of "Sewerage Capital Contribution Fund" (SCCF) managed by SPAN. According to the annual report published by SPAN, the amount of SCCF was reported as RM 562 million as at end of 2013 (SPAN, 2014).

From the above background, it was indicated that Malaysian sewerage strategy is migrating from decentralised system towards centralised system since the past decade, for better treatability and higher efficiency. The continuation of this direction is expected in the next decades to achieve the Government's long term vision of sustainable sewerage system. Besides, it was noted that huge allocation in terms of billion ringgits has been channelled to the sewerage industry in the past decade and more is expected in future. Thus the research on cost optimisation in sewerage industry is timely and in line with the country's need.

## 1.2 Problem Statements

In Malaysia, the Government emphasizes a lot on the quality of treated effluent from STP via more stringent effluent standards such as Environmental Quality (Sewage) Regulation 2009; however, no attention was given to the design flow of sewerage services especially the accuracy of the design peak flow factor (DPFF) adopted in the sewerage industry. Globally, much research had been done on the treatment processes, but very limited literature is available on the project costs in relation to the design flow and government policy (Eran and Ehud, 2006).

The DPFF formula prescribed in MS1228:1991 (SIRIM, 1991) has been adopted in the entire Malaysian sewerage industry. The same DPPF formula was also recommended in SSD and SPAN's guidelines (SSD, 1999 & SPAN, 2009a & 2009b). It should be noted that MS1228:1991 (SIRIM, 1991) has never been revised in the past 24 years since its publication. It was stated in SSD (1999) that the DPFF formula prescribed in MS1228:1991 is a predictive equation which has yet to be validated during the time of study, sewerage designers are allowed to use other equation which is valid and appropriate for a particular sewerage catchment. Unfortunately the above statement was unnoticed by all parties in the sewerage industry in Malaysia.

The impact of the DPFF to the sewerage industry is tremendous as it affect the sizing of the entire sewerage services including the secondary sewer, trunk sewer, force main, network pump station (NPS), STP etc whereby every component (civil and structure works as well as process, mechanical and electrical equipment) in the sewerage services are designed with additional capacity via the DPFF. However, based on the feedback from the industry, the DPFF recommended in the Malaysian sewerage design guideline is excessive and has not been achieved in actual flow condition in STP (Lim *et al.*, 2014). In addition, the result published by local researchers had further supported the claim by the industry that the DPFF had been over provided. According to these studies, the actual peak flow factor (APFF) and actual per capita flow in sanitary sewers were lower compared to the DPFF provided in Malaysian Standard MS1228:1991. As a result, sewerage system tends to be over designed and contributed to the increase in overall capital cost (Rahman *et al.*, 2007, Kamran *et al.*, 2013; Su & Ng, 2013; Su *et al.*, 2014). Besides, during the post construction stage, the sewerage services have not been fully utilized and most of the equipment is not operating at its optimum design efficiency. This has contributed to higher O&M cost for the entire service life of the sewerage utilities.

The EPU (2015b) has reported in the "Strategy Paper 16: Ensuring Quality and Efficient Water and Sewerage Services", 2015 that the two main challenges of sewerage services in Malaysia are as below:

i. High O&M cost whereby the revenue from sewerage tariff cannot cover the basic O&M cost of RM1 to 3 million per annum for each of the 6000 public STPs, hence the Government has to subsidize the concessionaire STP operators;

ii. Pollution to water body whereby 47.8% of point source pollution was caused by poorly operated multi point STPs. In addition, the pollution caused by non point source from septic tank and pour flush is immeasurable.

In order to improve the sustainability of the sewerage industry in Malaysia, EPU (2015b) has recommended in the strategy paper that the sewerage tariff shall be increased to reflect the actual O&M cost. In other words, the additional cost due to inefficiency in O&M of sewerage services especially STPs due to whatsoever reasons (including inaccuracy of DPFF) will be eventually paid by consumers.

## 1.3 Research Questions

From the problem statement, the key research questions to be addressed in the research approach are as below:

i. Is the APFF to the sewerage services in Malaysia lower than the DPFF?

ii. Is the Malaysian DPFF higher as compared to international peak flow factor (IPFF)?

iii. How much capital cost saving can be achieved in the sewerage reticulation projects in Malaysia if a more optimised peak flow factor (PFF), which is closer to the APFF is being adopted?

## 1.4 Research Aim and Objectives

The aim of this research is to prove that the DPFF adopted in the sewerage services is over provided as compared to the APFF and to evaluate its financial effect to the sewerage reticulation projects. The objectives of this study are as follow:

i. To analyze the APFF to sewerage system in Malaysia as compared to the DPFF and to recommend a more optimised PFF formula based on APFF
ii. To identify the standing of Malaysian DPFF formula (SIRIM, 1991) as compared to IPFF formulas;
iii. To assess the effect of the DPFF to the capital cost of sewerage reticulation projects

## 1.5 Scope of Study

The scope of this study shall include data collection from supervisory, control and data acquisition (SCADA) system of 5 selected large capacity CSTPs in Klang Valley and Penang. According to sustainability report 2012-2013 (IWK, 2014), there are 35 numbers of big STPs with capacity greater than 50,000 PE in Malaysia.

Statistical analysis of hourly flow data collected from the 5 CSTPs shall be conducted to calculate the APFF for the 5 CSTPs against their respective DPFF values. Based on the APFF for the 5 CSTPs, a more optimised PFF formula in lieu of the current DPFF formula shall be recommended. In addition, the calculated APFF for 5 CSTPs shall be compared against 6 IPFF formulas namely, Babbitt, Duncan, Gifft, Harmon, Johson, and Utah, besides Malaysian DPFF to evaluate the standing of APFF and DPFF against the IPFFs. From the comparison, 3 IPFFs closer to the APFF shall be shortlisted together with the proposed optimised PFF formula, for redesign of sewerage reticulation system by Professional Engineers using Manning equation, via standard engineering approach for 5 actual turnkey centralised sewerage projects (comprises 16 sewerage zones) undertaken by one of the largest engineering consulting firm in Malaysia, i.e. Sepakat Setia Perunding Sdn Bhd (SSP). Upon completion of redesign, engineers shall carry out quantity take off and update the actual tender bill of quantities (BQ) with quantities and standard rate published by the SSD (SSD, 2009) to obtain new capital cost for the sewerage projects under respective IPFFs. Cost comparison of capital cost generated from different PFFs for 5 sewerage projects in Malaysia as compared to that of the original design with DPFF shall be elaborated.

## 1.6 Research Significance and Benefits

This research is conducted under the Engineering Doctorate program with collaboration between SSP from the industry and Universiti Teknologi Malaysia (UTM) under the Industrial PhD scholarship by Ministry of Higher Education (MOHE) of Malaysia. With the university-industry collaboration, this study shall make use of the advantage of having actual sewerage projects undertaken by SSP in addition to UTM's strength as a research university. In addition, the engineering design skill held by the engineers (under supervision of Professional Engineers) in SSP shall be fully utilised in this research. The significance and benefits of this research shall be discussed in three categories, i.e. benefits to theory/ body of knowledge; benefits to the company and benefits to the industry and country.

### 1.6.1 Research Benefits to Theory/ Body of Knowledge

In this research, the current Malaysian DPFF prescribed in the MS122: 1991 and SPAN's MSIG (2009) which has never been tested shall be validated via actual flow data from the CSTP. From the findings from this research, a more optimised DPFF formula (which is closer to APFF) shall be recommended which will be beneficial to the theory and body of knowledge. The future researcher can further verified the proposed PFF formula against more actual flow data using the same approach.

### 1.6.2 Research Benefits to Sepakat Setia Perunding Sdn. Bhd.

SSP is the longest established engineering consulting firm in Malaysia, with more than 90 years experience. SSP was founded by Mr Steen Sehested, a Danish Engineer in 1924. The company was later renamed as Steen Sehested and Partners in 1960s before it was registered as the current Sepakat Setia Perunding Sdn Bhd in 1970s. SSP is a multi-discipline engineering consulting firm with more than 200 engineers (over 400 staffs), is also currently one of the largest engineering consulting firm in the country. Throughout the past 90 over years, SSP has successfully completed various projects in public and private sectors for its Clients and at the same time produce competence engineers to the industry via on job training.

SSP has undertaken some of the major sewerage projects in Malaysia and overseas such as 350,000PE Bayan Baru CSTP, 1.2 millionPE Jelutong CSTP, 900,000PE Yen So CSTP, Vietnam, 750,000PE Bunus CSTP, Kota Kinabalu sewerage projects, Petaling Jaya South sewerage reticulation project, Puchong sewerage reticulation project etc. From the vast experience in sewerage projects completed by SSP throughout the years, it is the professional responsibility of SSP as one of the leading consultant in the country to publish the project knowledge and experience in order to assist the authority to improve the current design guideline or standards and at the same time to improve the industrial's engineering design practice for the best interest of the country. In addition, the following are the benefits of the research to the company:

i. SSP's engineers may gain extra knowledge via in depth study on the engineering problems and solution in this research that enhance the competency of the engineers.

ii. research will encourage the publication culture among the engineers in the company.

iii. While meeting the business objectives of the company, the knowledge and experience from projects can be shared via publication in order to achieve cost optimisation and better efficiency in the sewerage services i.e. sewerage network and STP etc in future.

### 1.6.3 Research Benefits to Industry and Country

This research shall benefit the sewerage industry and country on the following:

i. To confirm the hypothesis that the DPFF prescribed in MS1228:1991 and SPAN guideline is over provided as compared to APFF and to evaluate the financial impact of the PFF to sewerage projects.

ii. Based on the above findings, it is expected that the saving in capital cost of the sewerage projects can be achieved via adopting a more optimised PFF in lieu of the current DPFF.

iii. It is believed that the findings of this study can convince the policy maker i.e. SPAN as the regulatory body in water and sewerage industry, on the substantiate amount of potential cost saving in the capital cost of sewerage projects in view of the RM10.3 billion sewerage projects have been recently approved by the Government under the RMK 10.

iv. Besides, the high O&M cost due to low operating efficiency of sewerage process mechanical and electrical (M&E) equipment as a result of over sizing of equipment can be avoided in future by adopting a more optimised DPFF.

v. Further to the research findings, further study is recommended especially on a nationwide scale DPFF to suit different sewerage catchment characteristic. Besides, further research on financial impact of PFF to the O&M cost in sewerage services i.e. NPS and STP shall benefit the industry in lowering the O&M cost in long run which will ease the financial burden of the Government and consumers.

Hopefully with the findings and recommendation from this research, SPAN with the support from the universities, STP operators and industries will initiate a full scale nationwide study to revise the current DPFF formula to reflect the actual flow characteristic of various sewerage services. This will benefit the entire industry and country in long term.

## 1.7 Operational Definitions

This dissertation is very specific to the sewerage industry in Malaysia. In order to help the reader to understand this dissertation, the operational definition (in the point of view of a wastewater engineer) for some of the technical terminology used in this dissertation are defined as below:

i. **Sewerage system**: normally used to describe the entire system that conveys the sewage generated from its source to the treatment plant. Thus it normally comprises sewerage reticulation, network pump station and sewage treatment plant.

ii. **Sewerage Reticulation**: also known as sewer network, comprises sewer (pipe) connected to the individual households (known as **secondary sewer**) to the bigger diameter sewer (known as **trunk sewer**). The combination of secondary sewers and trunk sewers is generally known as "sewerage reticulation" system. "Reticulation" is also commonly used in other infrastructure works such as water supply (as water reticulation system) and drainage system (as drainage reticulation system).

iii. **Gravity Sewer:** sewerage reticulation system is normally design to flow by natural gravity whereby the sewage flows from high point to low point via sewer laid with minimum gradient to achieve self cleansing velocity of 0.8 m/s. The sewer laid to flow by gravity is named as "Gravity Sewer". Gravity sewer can be constructed via open cut method or pipe jacking method, depends on the suitability of the site and the depth of pipe.

iv. **Network Pump Station (NPS)**: The invert level of the gravity sewer will get deeper with the increase length of collection sewer, when the depth of sewer reach a maximum depth set by authority (approximately 8m to 10m below ground level), NPS is normally introduced to lift up the sewage to a shallower invert level at a receiving manhole at suitable location and continue to flow by gravity to the designated destination. Besides, NPS is also introduced to suit the requirement of certain site topography such as river crossing, railway crossing, hill crossing etc. Sewerage designer will try to avoid NPS as much as possible as NPS will require life time operation and maintenance.

v. **Force Main**: the pipe in between a NPS and the receiving manhole is called force main. Force Main is operated by pressure created by the pumps in the NPS. As the force main is a pressurised sewer, it does not need to be laid with minimum gradient which is required in gravity sewer. Thus force main is normally laid at a shallower depth from the ground levels; it is normally constructed via open cut method.

vi. **STP**: is the final destination of the sewerage system whereby the sewage generated from its sources will be treated in STP to the effluent standard required under the law before released to the downstream water courses.

vii. **Diurnal Flow:** 24 hours diurnal flow in sewerage system is normally used to describe the 24 hour trend of average hourly flow (in $m^3$/hr) for a period of time. The diurnal flow normally comprises high point and low points at different hour of the day.

viii. **Quantity Take Off:** is an approach commonly used by Consulting Engineers or Quantity Surveyors (QS) to calculate the quantity of materials required in a particular scope according to the size and category of respective materials as shown on Tender Drawings. During the quantity take off, engineers/ QS will normally use a take-off sheet in the form of table to record the quantity before it is transferred into the Tender Bill of Quantities (BQ)

ix. **BQ:** is an important section in a tender document, whereby the design engineer/ QS has itemised the material or scope of work required with sufficient description and quantities to enable the Tenderers to price in their rate. The tender amount for each item will be calculated via multiplying the rate and the quantities stated in the BQ. The final cumulative amount developed from the BQ will form the Tender price (under a conventional contract)

## 1.8 Structure of Dissertation

This dissertation is divided into five chapters. Chapter 1 is the introductory chapter, which describes the research background, problem statements, objectives to be achieved, research significance and benefits, scope of research and the structure of the dissertation. Literature review in Chapter 2 presents the topics related to the research project including the sewage flow, PFF formulas adopted in sewerage industry etc.

Chapter 3 presents the research methodology employed i.e. the data processing and analysis to calculate the APFF for CSTPs, engineering approach in redesign of sewerage projects and financial analysis via actual Turnkey tender BQ to evaluate the cost implication.

In Chapter 4, the result of statistical analysis to calculate the APFF in selected CSTP and subsequent financial analysis on 5 actual sewerage projects using 3 selected IPFF formulas shall be presented. Chapter 5 summarises the results and findings obtained from the previous chapters. This chapter also highlights contributions to the knowledge and industry besides giving recommendations for further study.

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