AN IMPLEMENTATION PLAN OF TOTAL MAXIMUM DAILY LOAD (TMDL) AND WATER QUALITY MODELLING APPROACH AT THE MELAKA RIVER, MALAYSIA

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ABSTRAK

Sungai Melaka merupakan salah satu tempat menarik bagi tarikan pelancongan dan telah disenaraikan sebagai sejarah dan warisan UNESCO pada Julai 2008. Walau bagaimanapun, perkembangan pesat, aktiviti urbanisasi dan pelancongan telah memberi impak negatif kepada Sungai Melaka, seperti beberapa kes ikan mati, air sungai berwarna hitam dan berbau busuk telah dilaporkan. Oleh itu, strategi yang berkesan perlu dibangunkan untuk memastikan pencemaran yang masuk ke sungai dapat diukur dan boleh diurus. Penyelidikan ini bertujuan untuk mengkaji jumlah maksimum beban pencemar yang dibenarkan masuk ke dalam sungai, berdasarkan piawaian kualiti air dengan melaksanakan jumlah beban harian maksimum (TMDL) di Sungai Melaka, Malaysia. Pendekatan TMDL di Sungai Melaka, telah dijalankan dengan penilaian kualiti air dan pemodelan kualiti air sebagai alat perancangan. Kerja ini telah dilakukan dengan mengumpul data kualiti air dan data hidraulik dari empat kali persampelan air dan kutipan data dari agensi kerajaan. Data fizikokimia dikumpulkan dan dianalisis. Parameter fizikal iaitu konduktiviti, saliniti, suhu, dan jumlah pepejal terampai (TSS) dikumpulkan dalam kajian ini. Selain itu, parameter kimia seperti permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), oksigen terlarut (DO), jumlah fosforus (TP), fosfat (PO_4^{3-}), jumlah nitrogen (TN), dan ammonikal nitrogen (NH_3-N) juga dikaji. Kepekatan COD (365.54 mg / L). telah dijumpai sebagai parameter tertinggi yang menyumbang ke dalam sungai terutama di kawasan hiliran. Analisis indeks kualiti air (WQI) telah mengklasifikasikan Sungai Melaka di bawah sungai Kelas III. Oleh itu, TMDL bagi Sungai Melaka ditetapkan untuk mencapai Kelas IIB, yang sesuai untuk aktiviti rekreasi dengan sentuhan badan. Analisis korelasi Pearson menunjukkan korelasi positif yang signifikan berlaku antara COD dan DO (nilai r 0.520, 0.669), COD dan TP (nilai r 0.606), dan COD dan TSS (nilai r 0.740, 0.975, 0.608), dan korelasi negatif yang signifikan antara COD dan BOD (nilai r -0.545). Hal ini menunjukkan penurunan COD semasa pendekatan TMDL, dapat menurunkan kepekan parameter lain, serta memperbaiki kualiti air Sungai Melaka. Terdapat 10 senario yang dicipta untuk analisis pengurangan beban COD dengan menggunakan Simulasi Sungai InfoWorks (RS) sebagai alat perancangan untuk TMDL, dan Senario 9 dipilih sebagai syarat optimum untuk mencapai Kelas IIB di Sungai Melaka, dengan TMDL adalah 21387.30 kg/hari, WLA adalah 8131.99 kg/hari dan MOS adalah 2138.73 kg/hari. Strategi kawalan di sumber tetap berpunca dan sumber tidak tetap berpunca telah dicadangkan. Strategi kawalan sumber tetap berpunca dicadangkan untuk melaksanakan loji rawatan dengan kombinasi system A_2O (Anaerobik/Anoksik/Oksik) dan SBR (penjujukan sistem reaktor), manakala kawalan sumber tidak tetap berpunca dicadangkan untuk menggunakan sistem Pengurusan Amalan Terbaik (BMPs). Program pemantauan yang efekti dan kerangka waktu dicadangkan untuk menilai keberkesanan dan keberhasilan bagi program TMDL. Di samping itu, dari analisis kaji selidik, menunjukkan bahawa walaupun 69% dari pihak yang berkepentingan mempunyai pengetahuan tentang TMDL, namun hanya 2% yang mempunyai pemahaman yang lebih mendalam mengenai proses TMDL. Sedangkan 59% dari pihak yang berkepentingan percaya bahawa pelaksanaan TMDL akan memberi kesan yang signifikan terhadap pihak pentadbir dan ekonomi. Cabaran-cabaran pada masa depan yang perlu dihadapi dari segi cabaran asas dan penglibatan pihak berkepentingan turut dibincangkan dalam kajian ini. Kesimpulannya, hasil yang dibentangkan dalam kajian ini dapat membantu meningkatkan kualiti air di Sungai Melaka, serta memulakan pendekatan pelan pelaksanaan TMDL di Malaysia.

ABSTRACT

Melaka River has become one of the most popular places for tourism attraction and has been listed as historical and heritage of UNESCO in July 2008. However, the rapid development, urbanisation and tourism activities gave negative impact to the Melaka River, such as several cases of fish kills incident, smelly and black color of river has been reported. Thus, an effective strategy needs to be developed to ensure the pollution enters the river is accountable and manageable. The research aims to study maximum amount of pollutant allowed to enter the river, within the water quality standard by implementing the total maximum daily loads (TMDL) approach at Melaka River, Malaysia. The TMDL approach at Melaka River, has been carried out with the water quality assessment and water quality modelling as the planning tools. This work has been done by collecting the water quality data and hydraulic data from the four times water quality sampling and data from the government agency. The physicochemical data were collected and analyses. The physical parameter which is conductivity, salinity, temperature, and total suspended solids (TSS) were collected in this study. Besides, the chemical parameter such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), total phosphorus (TP), phosphate (PO_4^{3-}), total nitrogen (TN), and ammoniacal nitrogen (NH_3-N) were also studied. The COD concentration (365.54 mg/L). was found out as the highest parameter contributed into the river especially at the downstream. From the Water quality index (WQI) analysis have classified the Melaka River under Class III river. Therefore, TMDL for the Melaka River was assigned to achieved Class IIB, which suitable for recreational activities with body contact. The Pearson correlation analysis shows strong significant positive correlation occurs between COD and DO (r-value 0.520, 0.669), COD and TP (r-value 0.606), and COD and TSS (r-value 0.740, 0.975, 0.608), and strong significant negative correlation between COD and BOD (r-value -0.545). This shows that the improvement of COD during the TMDL approach, can significantly improve the other parameters, as well as the water quality of Melaka River. There were 10 scenarios created for COD loads reduction analysis by using InfoWorks River Simulation (RS) as the planning tools for TMDL approach, and Scenario 9 was selected as the optimum condition to achieved Class IIB at Melaka River, with the TMDL is 21387.30 kg/day, WLA is 8131.99 kg/day and MOS is 2138.73 kg/day. The control strategies at point sources and nonpoint sources were suggested. The point sources control strategies were suggested to implement the treatment plant with a combination of A_2O (Anaerobic/Anoxic/Oxic) and SBR (sequencing batch reactor) system, while the nonpoint sources control was proposed to apply the Best Management Practices (BMPs) systems. The effective monitoring program, and time frame were proposed to evaluate the effectiveness and successfulness of TMDL approach. Besides, from the survey analysis, shows that even though 69% of stakeholders have knowledge on TMDL, however, only 2 % has deeper understanding on the TMDL process. Whereas 59% of stakeholders believes that the implementation of TMDL approach will significantly impact the governing body and economy. The future challenges need to face in terms of fundamental and involvement of stakeholders was discussed in this study. In conclusion, the result presented in these studies may facilitate to improve the water quality of the Melaka River, as well as initiated the TMDL implementation plan approach in Malaysia

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LIST OF ABBREVIATIONS

1-D	1-Dimensional
2-D	2-Dimensional
3-D	3-Dimensional
A	Algae
A_2O	Anaerobic/Anoxic/Oxic
ANC	Acid Neutralizing Capacity
APHA	American Public Health Assessment
BKSA	Badan Kawal Selia Air
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
BOD_5	Biochemical Oxygen Demand 5 Days
C	Conservative Mineral
Ca	Calcium
CBOD	Carbonaceous Biochemical Oxygen Demand
CCME	Canadian Council of Ministers of The Environment
chl-a	Chlorophyll A
Cl	Chloride
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DID	Department of Irrigation and Drainage
DO	Dissolved Oxygen
DOE	Department of Environment
EC	Escherichia Coli
EDSS	Environmental Decision Support System
EFDC	Environmental Fluid Dynamic Codes
EPA	Environmental Protection Agency
EQA	Environmental Quality Acts
FC	Faecal Coliform
FOFEA	First-Order Error Analysis
FRI	Fisheries Research Institute
GIS	Geographic Information System

GPS	Global Positioning System
GQA	General Quality Assessment
H_2SO_4	Sulphuric Acid
HPS	Highly Polluted Sites
InfoWork RS	Infowork River Simulation
InfoWorks ICM	Infoworks Integrated Catchment Modeling
IRBM	Integrated River Basin Management
IWK	Indah Water Konsortium
IWRM	Integrated Water Resources Management
JKR	Malaysia Public Works Department
JKR	Ministry of Works
JUPEM	Department of Survey and Mapping
KeTTHA	Ministry of Energy, Science, Technology, Environment and Climate Change
LA	Load Allocation
LPS	Low Polluted Sites
LUAS	Lembaga Urus Air Selangor
MBR	Membrane Bioreactor
Mg	Magnesium
Mn	Manganese
MOS	Margin of Safety
MPS	Moderately Polluted Sites
MSMA	Urban Storm Water Management Manual
N	Nitrogen
NAHRIM	National Hydraulic Research Institute of Malaysia
NC	North Carolina
NH_3-N	Ammoniacal Nitrogen
NO_2	Nitrite
NO_3	Nitrate
NPS	Nonpoint Sources
NRE	Natural Resources and Environmental Ministry
NSF	National Sanitation Foundation
NWQS	National Water Quality Standard

NWR	National Water Resources
NWRP	National Water Resources Policy
PAH	Polyaromatic Hydrocarbon
PBT	Local Authority
PLANMalaysia	Department of Town and Country Planning
PO_4^{3-}	Phosphorus
PPSPM	Perbadanan Pembangunan Sungai dan Pantai Melaka
ppt	Part per thousand
PS	Point Sources
Q	Flow of The River
RBMU	Road Map Management Units
S	Sulphur
SBR	Sequencing Batch Reactor
SO_4	Sulphates
SOD	Sediment Oxygen Demand
SPAN	National Water Services Commission
SRDD	Scottish Research Development Department
SWAT	Soil and Water Assessment Tool
T	Temperature of river
TMDL	Total Maximum Daily Loads
TN	Total Nitrogen
TO	Total Oxidized
TP	Total Phosphorus
TSS	Total Suspended Solid
USA	United State of America
USDA	United States Department of Agriculture's
USEPA	United State Environmental Protection Agency
WLA	Waste Load Allocation
WQI	Water Quality Index
WQS	Water Quality Standards

CHAPTER 1

INTRODUCTION

1.1 Introduction

Surface water can be described as any water body that flows or stands on earth surfaces such as streams, river, and reservoirs (Mustapha et al., 2013). The river is usually located at the environment with highly populated and industrialized areas, since it has the resources essential for the human usage, agricultural, and industry (Othman et al., 2012; Mustapha et al., 2013; Aris et al., 2013). However, the water quality of the river was affected by a wide range of natural and human pollution flow into the river, that disrupted the water quality of the river (Kamaruddin et al., 2015). The sources of pollution may be contributed from an anthropogenic source such as sewage discharges, agricultural runoff, industrial disposal, human wastes and natural process (Aris et al., 2013).

The sources of river pollution can be categorised into two types, which are point sources and nonpoint sources. The pollution from the one source and can be recognised, that usually flowing into the river and sea, usually known as point sources (Environmental Protection Agency [EPA], 2012). For instance, wastewater effluent is from municipal and industrial run-off, leachate is from waste disposal site, run-off is from animal wastes, mines, oil fields, un-sewerage industrial site, run-off from construction sites, storm sewer outfalls from cities, overflow of combined storm and sanitary sewers were the types of point sources (Mustapha et al., 2013). Whereas the nonpoint sources were defined as 'diffuse' pollution and came from those inputs and impacts which occur over a wide area and are not easily attributed to a single source (EPA, 2012). It resulted from the land runoff, precipitation, atmospheric deposition, drainage, and hydrologic modification (Mustapha et al., 2013). It is often more difficult to control nonpoint sources than point sources pollution. The term "nonpoint source" was defined as any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act, United State Environmental Protection Agency (United State Environmental Protection Agency [USEPA], 2012).

The water quality of river becomes one of the crucial issues as it is one of the ecological and globally concerns due to its contribution as an essential resource for human daily activities (Ismail et al., 2016). The discharge of wastes into the river has caused the depletion of water quality that leads to unhealthy natural resources and affects the overall environment, thus become a global concern (Aris et al., 2013). There were about 3.4 million people died every year by waterborne disease such as cholera, typhoid fever, hepatitis A, and cancer, the implication from lack of safe drinking water and sanitization, a report from The World Health Organization (Aris et al., 2013).

Malaysia is one of the renowned ongoing developing countries in South East Asia, and the major water demand comes from agriculture, industries as well as a domestic sector (Department of Environment [DOE], 2017). The wastewater discharged from the manufacturing industry, agro-based industry, domestic sewage, animal husbandry, mining activity as well as surface runoff from land clearing and earthworks activity were the main sources of pollution and led to river pollution in Malaysia (Aris et al., 2013; Kamaruddin et al., 2015). The suspended solid has become the most sources of pollution with 42% from the bad management of land clearance activities, followed by biological oxygen demand (30%) from the industrial disposal, ammoniacal nitrogen (28%) from the animals farming waste and sewage disposal (Zali et al., 2011; Kamaruddin et al., 2015).

Based on the previous study conducted by DOE Malaysia in the year of 2010, it has found out that 527 (50%) rivers were clean, 417 (40 %) rivers were slightly polluted, and 111 (10%) rivers were polluted from 1055 water quality monitoring stations located at 570 rivers in Malaysia (Amneera et al., 2013). While during the year of 2016, 224 rivers were found clean, 207 rivers were found slightly polluted, and 46 rivers were found polluted (DOE, 2017). It shows the numbers of polluted river increase due to the rapid development, urbanization and development of industrial and commercial sectors, which also increase the sources of pollution in the rivers.

Nowadays, water pollution issues in Malaysia are one of the main concerns since it becomes more serious. Mostly, the water from the rivers in Malaysia was used extensively for domestic needs, agriculture, drinking, cooking, washing, and daily needs (Zali et al., 2011). Melaka River is one of the important and attractive rivers in Malaysia. It has become an attraction for tourism activity due to the historical place, unique heritage building and cruising activities along the river. The high density of activities and population occurs around the Melaka River has increased the pollution sources and polluted the river. Therefore, Melaka River was selected as the target area to study the impact of reducing the pollution sources into the river by using water quality model towards the TMDL approach.

One of the methods to overcome the river pollution is by doing total maximum daily loads (TMDL) approach. TMDL can be defined as the highest level of pollutant that can be accepted by the river without violating the water quality standard (Peterson et al., 2008). TMDL has been initiated by the United States Environmental Protection Agency (USEPA), in 1972 under 303(d) of Clean Water Act (CWA) list (Liang et al., 2016). The TMDL implementation plan can help to improve and protect the water quality of the Melaka River, as well as achieved the target water quality standard. By doing the TMDL approach, the pollution sources such as point and nonpoint sources in the watershed were easily managed and control. The mathematical modelling are important tools during the development of a TMDL implementation plan (Wang et al., 2015). The water quality model was an integral part of the development of a TMDL implementation plan. The modelling process provides the decision support system for loads reduction analysis, during the development of TMDL.

The water quality model was usually used as the water quality planning tools in managing the watershed (Hossain et al., 2013). The main purpose of the water quality model was to analyse and forecast the observed effect of any changes occur in the river. The water quality models can be used to observe the changes in physical, chemical and biological, as well as relationships of reducing the pollution load and the water quality in rivers (Zainuddin et al., 2010). The analysis of the model can be used to create scenarios for the decision-making process (Hassan, 2005; Song & Kim, 2009; Zhao et al., 2013). The scenarios of load reduction were the prediction of water quality condition of the river at a different level of pollution loading, which is important as to propose the defensive strategy for maintaining the health of the river and environmental impact assessment

(Wang et al., 2015). The water quality model has played a significant role to achieve water quality target and to assist in the management process.

The water quality model has been widely used in Malaysia. There were many types of model been developed and implemented to overcome the environmental problem such as water quality issues, flooding, and river management. Some studies recently have integrated the water quality model with another type of supporting application such as Geographic Information System (GIS) and Soil and Water Assessment Tool (SWAT). In Malaysia, the water quality model was widely used for water quality assessment. For examples, a study of low flow analysis at Sg Selangor, and to calculate the amount of pollutant loading needed to achieve the water quality standard desired at Sg Tebrau by using the QUAL2E model (Mohamed, 2008). Besides, another study was done at Sg Juru, Penang by using one-dimensional InfoWork RS model, to analyse pollution characteristic along the river and the impact of tidal to the water quality of river (Toriman et al., 2011). According to Mah et al. (2007); Toriman et al. (2010) and Toriman et al. (2011), the study of water quality model by using InfoWork RS was well established and well known in Malaysia.

1.2 Problem statement

Water quality and pollutions of rivers were the most common and related issues had been concerned in Malaysia. Nowadays, the awareness of the importance of having good watershed management of ecosystems had increased among public and government agencies. Melaka River is one of important tourism attraction in Malaysia. However, the rapid development and urbanization process around the study area, which contributed by the point and nonpoint sources of pollution, have significantly degraded the water quality of the Melaka River. The water quality of the Melaka River has been deteriorating with the increase of pollution sources. Recently, Melaka River has been reported to experience environmental pollution such as the fish kill incident (Hua, 2015). There were hundreds of wild marines, and freshwater fishes were reported floating and found dead in the Melaka River due to the dissolved oxygen concentration was low in the river (Rosli et al., 2015). When the rapid development and increase of population happened, without the presence of a specific monitoring system and watershed management strategies for the preservation of the river, will lead to the decline in the water quality.

The main sources of pollution were identified from sewage, domestic waste from commercial and residential areas, waste from wet markets and industries (Hua, 2015). While, the nonpoint sources pollution was coming from the agricultural, construction and municipal areas into the Melaka River (Rosli et al., 2015). Based on the water quality monitoring data conducted by the DOE on the years of 2011 to 2013, the water quality status was in Class III, particularly near the river downstream of the Melaka City (Rothenberger et al., 2014). While, the latest water quality monitoring by DOE, shows that the Melaka River was still classified as Class III river for the year 2017 (DOE Melaka States, 2017). It is important to control the water quality of Melaka River, since the tourism activity is the main attraction and beneficial to the state and country. Besides, by having a beautiful and clean river, was important to show a good image to the tourist. In this present work, the TMDL approach proposed to be implemented at Melaka River focused only on Chemical Oxygen Demand (COD), in order to achieve the desired water quality standard of Class IIB.

1.3 Objectives of the study

The aim of this study is using the approach of TMDL implementation plan framework to control the COD loads into Melaka River. The present work has four main objectives, as follow:

i. To identify the spatial and temporal variation of surface water quality in the Melaka River.

ii. To analyse the water quality index of the Melaka River by using formula established by the Department of Environmental (DOE), Malaysia.

iii. To develop a water quality model of the Melaka River by using InfoWork RS version 10.5 for COD loads reduction analysis.

iv. To design a TMDL implementation plan for suitable watershed strategies in the Melaka River.

1.4 Significant of study

The strength of this research lies on its specific focus on the determination of maximum allowable COD loads into the Melaka River by using InfoWork RS version

10.5 software, for the TMDL implementation plan approach. The study on the maximum allowable COD loads has been very important in sustaining the aquatic ecosystem, where it was related to the maximum amount of pollutants that can be supported by the river in order to meet their safety level of the water quality (Liang et al., 2016). Since Melaka River was one of the tourist attractions in Malaysia and listed by UNESCO in July 2008 as historical and heritage place (Hua, 2015), therefore, it was a very significant study area for this study. Every year, the numbers of tourist came to Melaka has increased. There was a lot of attraction occurring along the Melaka River such as river cruise and sightseeing activity, historical building and trishaw transportation (Hua, 2015). However, the rapid development, urbanization, and tourism activities have given an adverse impact on the water quality of the Melaka River.

The present work has contributed to the TMDL implementation plan approach by collecting the water quality data, river cross-section data, and water depth data at the Melaka River, as well as its tributaries which are Putat River, Cheng River, and Durian Tunggal River that gives a significant amount of pollutant loads into the Melaka River. By using the water quality data collected, the Pearson Correlation Coefficient analysis was done to provide the significant information on the relationship among the parameter, and the origin of the pollution sources (Sharma et al., 2014). Furthermore, the WQI analysis serves as effective tools to inform the non-technical stakeholders the status of Melaka River in a single value that can be easily understandable (Wanda et al., 2016). Besides, this study provides a convenient water quality model, which is InfoWorks RS version 10.5 as planning tools for TMDL implementation plan that can easily be adapted to other rivers in Malaysia. The TMDL implementation plan for Melaka River was beneficial for the management agencies to overcome and encounter the pollutants load into the river according to the suggested implementation plan. Furthermore, this study also contributed to suggest a suitable improvement in terms of effective monitoring strategies and time frame for the TMDL implementation at the Melaka River, as well as for other rivers in Malaysia.

1.5 Scope of study

Based on the objectives of this study, the scope of this study has been identified and listed as follows:

The scope of study for objective 1: To identify the spatial and temporal variation of surface water quality in the Melaka River.

i. The study area was recognised as Melaka River, which was located in the Melaka State, Malaysia.

ii. The water quality data, the cross section of river data and condition of river based on sampling conducted, secondary data such as water quality monitoring data from government agencies, hydraulic and hydrology data, and additional information related to the study of the Melaka River were collected.

iii. The in-situ data such as dissolved oxygen, pH, conductivity, flow rate, depth, salinity, and temperature were collected at the sampling site.

iv. The laboratory analysis for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Phosphorus (PO_4^{3-}), Ammoniacal Nitrogen (NH_3-N), and Total Suspended Solid (TSS) parameter was done.

v. The statistical analysis was done by using SPSS model, which was the Pearson Correlation Coefficient to identify the correlation between parameters.

The scope of study for objective 2: To analyse the water quality index of the Melaka River by using the formula established by the Department of Environmental (DOE), Malaysia.

i. The WQI for Melaka River was calculated using data collected, and the result of WQI was analysed to determine the classes of the Melaka River.

The scope of study for objective 3: To develop a water quality model of the Melaka River by using InfoWorks RS version10.5 for COD loads reduction analysis.

i. The hydraulic and water quality model was developed using the available data by using InfoWorks RS software.

ii. Based on the modelling, the scenarios of COD loading at a different concentration was created.

iii. The most optimum and suitable scenario for COD loads reduction to achieve the target water quality standard was chosen for the TMDL implementation plan.

The scope of study for objective 4: To design a TMDL implementation plan approach for suitable watershed strategies in the Melaka River.

i. The implementation plan of TMDL in the United States and Asia were studied and compared.

ii. The suitable implementation plan of TMDL for Malaysia was recognized and suggested to be adopted at the Melaka River for COD loads reduction.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers the comprehensive review and argument on TMDL development and approaches in the United States of America (USA) and other countries such as China, South Korea, Japan, and Taiwan. The origin and recent implementation of TMDL were discussed, and the evolution of the TMDL approach from standard implementation to adaptive implementation has been criticised in this chapter. Besides, this chapter also studies the TMDL implementation in the United States as well as in Asian countries such as South Korea, China, and Taiwan. The view of TMDL in both regions gave a better picture of the TMDL implementation plan approach in Malaysia. As the TMDL planning tools, the water quality model aspect was also discussed in this chapter. It is important to know the roles of the water quality model in the TMDL approach, hence InfoWorks River Simulation (RS) version 10.5 was used in this study. Also, the compatibility of InfoWorks RS version 10.5 for TMDL approach in Melaka River was been studied. The water quality model needs to be well applied since the TMDL program was affected by the modelling results. The previous systems of TMDL program were studied to ensure a good and excellent TMDL implementation plan can be developed in Melaka River, Malaysia. According to the study of the literature reviews, the need for the study was defined and clarified. From the previous study, the same problems and mistakes during the past TMDL implementation can be avoided.

Furthermore, the overview of the Melaka River as the study area for this research was clarified in this chapter. The knowledge of Melaka River was present, to give a better understanding of Melaka River condition, and the needs for TMDL implementation plan. The TMDL was initiated based on the water quality impairment. Therefore, it was important to review the water quality parameter, which determines the river health status. The water quality index analysis (WQI) and statistical analysis were well defined, to show how these two types of analysis helped in the development of the TMDL program. On the other hands, the current Malaysia watershed management program was also studied. The current and existing watershed management program can be improved with the TMDL approach and helps to enhance the ability to manage the river in Malaysia (Singh, 2009).

In order to study the TMDL approach, there were few steps required to be done. Firstly, the determination of impairment river, and the TMDL target is set up (Wang & Bi, 2016). The water quality index and statistical analysis helped to determine the TMDL target. The collection of water quality data as input in water quality models such as temperature, pH, salinity, conductivity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), depth of the river, the flow rate of the river, and cross-section of the river. All this data was important during the model development, as well as the determination of the target water quality parameter for pollutant loading reduction. The TMDL approach required to select a suitable scenario from a water quality model for pollutant loads reduction analysis. By using the calculated reduction of pollutant loading needed, the TMDL approach was suggested (Cho & Lee, 2015).

2.2 TMDL Implementation Plan

TMDL is a term used to describe a value of the maximum amount of a pollutant a body of water can receive while still maintaining the water quality standard and an allocation of that load among the various sources of that pollutant (Petersen et al., 2008; Dabney et al., 2012). TMDL can also determine as the assimilative capacity of the river can be quantified, and the waste load allocation to ensure the assimilative capacity are not exceeded (Wang & Bi, 2016). TMDL was introduced by the United States Environmental Protection Agency (USEPA), to identify the water body of rivers that do not meet the water quality standard under section 303d of the Clean Water Act (CWA) (Camacho et al., 2018).

There were important elements required in TMDL such as name and geographic location of impaired waterbody, the identification of pollutant and target water quality standard, the amount of pollutant load that meets water quality standards, waste load allocations, load allocations, margin of safety, consideration of seasonal variation, future growth allocation, and lastly implementation plan (Wang & Bi, 2016). All these elements were required to be fulfilled during the development of TMDL by the state.

TMDL development process has been evolved from time to time. The standard procedure for development has been improved. The TMDL programs were usually known as “learning while doing” program for many planners (Alameddine et al., 2011). TMDL was designed to improve the impaired water body and maintain the water quality through the establishment of pollutant-specific allowable loads, based on the reduction of pollution from both point and nonpoint sources (Wang et al., 2015). Impairment means that the water cannot support a designated use, such as fishery, recreation, irrigation, or public drinking supply (Wagner et al., 2007). The evolution of the TMDL process has enhanced the capability of the programmed to restore the water quality of the river.

TMDL was evolved, which was started with standard implementation and then developed into an adaptive implementation plan as shown in Figure 2.1. The standard TMDL implementation plan was a basic process of TMDL, start with the identification of impaired water bodies and classify each body with respect to the degree of limitation of use due to impairments. The impairments were analysed according to the desired target for water quality of the river, collecting the water quality data, creating the suitable scenario for water quality improvement, and developing the implementation plan based on target water quality. After the establishment of TMDL, the progress was monitored. In contrast, the adaptive TMDL program will keep on evaluating the implementation program, by using the monitor and modelling the water quality improvement, refine control of pollution reduction programmed.

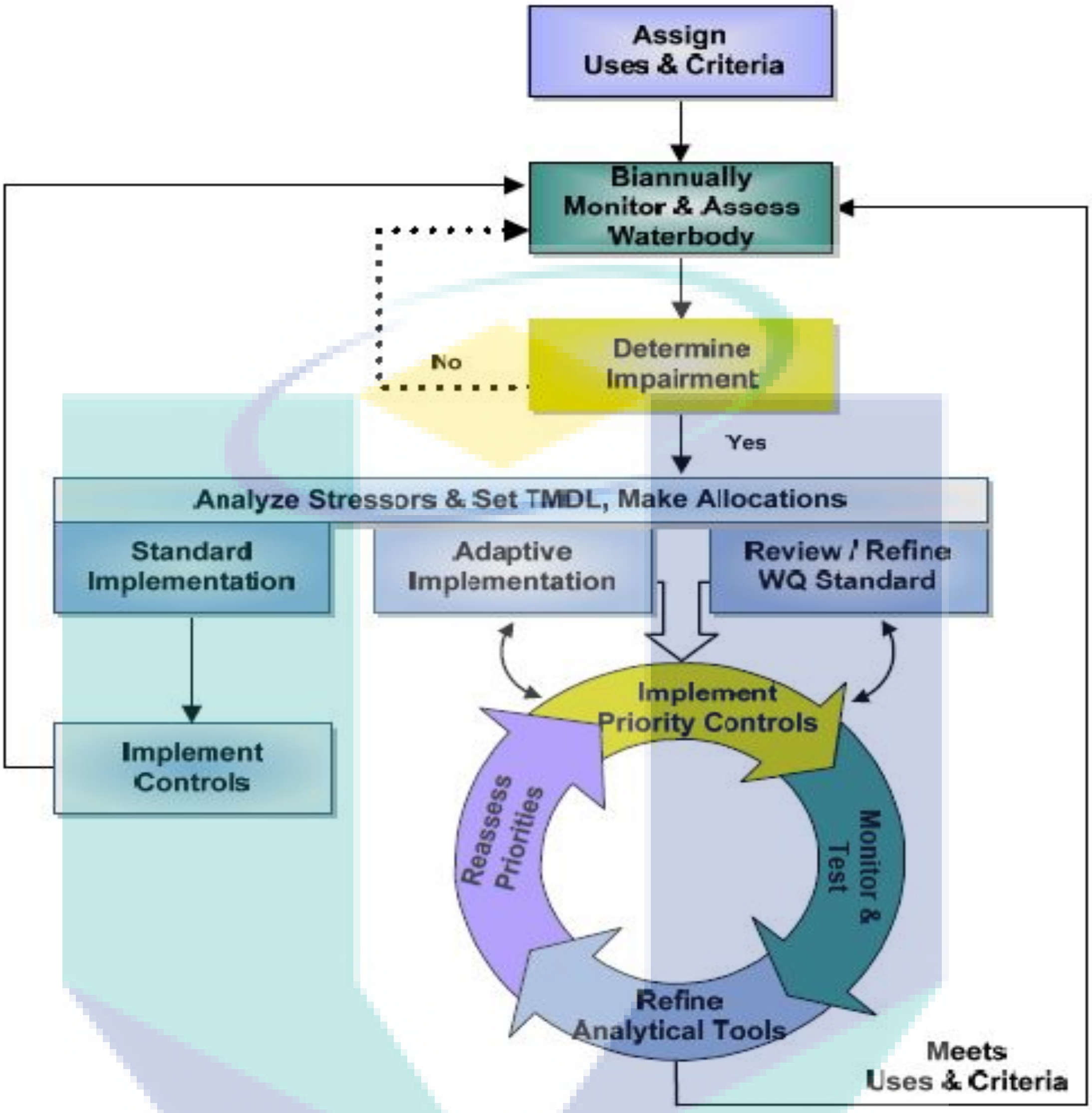


Figure 2.1 The comparison of TMDL implementation process between standard and adaptive watershed management TMDL implementation plan.

Source: Freedman et al. (2008).

The adaptive watershed management of TMDL used the concept of " learning while doing" as the program kept on evaluating the effectiveness and successfulness of TMDL (Freedman et al., 2008). The probabilistic basis in adaptive watershed management plans was an important element in the TMDL plan (Patil & Deng, 2011). The complexity of the ecosystem can be reduced by using learning while doing concept, where the experimentation from management actions was improve based on a further study (Patil & Deng, 2011). The implementation in adaptive management can be a process through time, compared to stay as a singular action as in standard implementation (Freedman et al., 2008). The lesson learned concept had been applied to improve the

TMDL, by viewing it as an ongoing process and flexible process, and the decision-making process can be made simultaneously with the management objective (Stow et al., 2011).

The TMDL approach at Melaka River was suggested for implementing the adaptive TMDL strategies, which benefits in supporting the inadequate data collection and predictive tools during the process of identifying and analysing the pollution problem. Besides, it is also can help the stakeholders to determine the need to revise the TMDL program based on additional data collection (Freedman et al., 2004). In comparing with the standard TMDL approach, the TMDL program was evaluated as a singular process, where the TMDL was considered successful only if the water quality problems were clearly identified, and the proposed control was known to be effective (Freedman et al., 2004). There were several regions in the United States have implemented the adaptive TMDL approach, for examples at the Savannah River of Georgia have addressed the adaptive TMDL program for mercury in fish consumption advisories, while at the Lake Champlain of Vermont have to apply the adaptive TMDL for phosphorus control, and at the Snake River of Idaho the adaptive TMDL was develop for numerous sources of nutrient enrichment (Freedman et al., 2004).

By doing the adaptive management in TMDL, the long-term monitoring process can facilitate the development of the TMDL program in the future. The standard implementation of TMDL shows that it was hard to identify the successfulness of the program without further monitoring program. In this present work, the development of TMDL at Melaka River was suggested to use an adaptive management framework with several modifications suitable with water quality management in Malaysia. The development of adaptive management of TMDL at Melaka River will help in monitoring the improvement and progress of the program at the river.

2.2.1 TMDL approach in the United States

TMDL program was originated from the United States and has been well implemented. In the United States, the TMDL program was divided into 10 regions, and the program was conducted by authorities in the region. All the impairment of the river was listed in CWA 303(d) list and needed to develop TMDL, to restore the waterbody. All the reports of TMDL were submitted to EPA for the reviewing process. The list of the coverage area of TMDL in each region is shown in Table 2.1. There were only 29.1% of all rivers and streams has been assessed in the United States, in which there were 51.4 % of rivers and streams were impaired (EPA, 2018c). The main causes of impairment were pathogens, followed by sediment, nutrient, and organic enrichment. According to EPA, the numbers of approved TMDLs by the state since October 1, 1995, was 73, 999 TMDLs program (EPA, 2018c).

Table 2.1 Areas covered for each region in the United States.

Region	**Area**
Region 1	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont and 10 tribal nations
Region 2	New York, New Jersey, Puerto Rico and the U.S. Virgin Islands
Region 3	Pennsylvania, Maryland, Delaware, Virginia, West Virginia and the District of Columbia
Region 4	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee and 6 Tribes
Region 5	Great Lakes and Upper Midwest states: Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin and 35 tribes
Region 6	Arkansas, Louisiana, New Mexico, Oklahoma, Texas and 66 tribes
Region 7	Iowa, Kansas, Missouri, Nebraska and Nine Tribal Nations
Region 8	The states of Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming, 27 tribal nations
Region 9	Arizona, California, Hawaii, Nevada, Pacific Islands, 148 Tribal Nations
Region 10	Alaska, Idaho, Oregon, Washington and 271 native tribes.

Source: EPA (2018c)

There were many TMDL program was done in the United States, which can be a guideline for the TMDL approach in Malaysia, especially at the Melaka River. There were several key features that need to be considered while developing TMDL, which is the impairment of water quality parameter, the suitability of the water quality model used, and the involvement of stakeholder. Usually, these were the three main elements used to determine the effectiveness of TMDL analysis. A study done by Zou et al. (2006), shows the TMDL approach at Wissahickon Creek basin of Pennsylvania, by using integrated hydrodynamic EFDC and water quality model WASP/EUTRO, to solve the excess nutrient levels cause from higher biological activities of excessive periphyton growth, that led to the dissolved oxygen impairment. Based on modelling analysis, 99% reduction of phosphorus has reduced the periphyton growth, and increase DO concentration. This study has proved that the suitable TMDL target parameter can significantly improve the water quality of the river.

According to Fakhraei et al. (2014), in their TMDL study at Adirondack region of New York, they evaluate the chemical recovery in lakes ecosystem based on the acidity level and scenarios of potential depositions by using biogeochemical model (PnET-BGC), they stated three main assumptions which were (1) reducing atmospheric deposition of Sulphur (S), (2) reducing atmospheric deposition of Nitrogen (N), or and (3) combination of reducing atmospheric deposition of S and N with 0, 10, 25, 40, 50, 60, 75, 90, 100% reduction. However, they found out that there was a significant impact on controlling S deposition in recovering the lake's ecosystem, rather than controlling the N deposition. Based on his study, the TMDL provides a reliable option to recover the ecosystem and good prediction on the impact of future pollutant loading to the ecosystem.

In other cases, a study was done by Bowen and Hieronymus (2003), at Neuse River Estuary of North Carolina who was faced with high chlorophyll a and low dissolved oxygen concentrations, which is required for TMDL development. This river has experienced dramatic fish kills in mid-1980 and early 1990s (Alameddine et al., 2011; Bowen & Hieronymus, 2003). In this study, the TMDL was developed to reduce the violation of chlorophyll by addressing the reduction of nitrogen loading. CE-QUAL-W2 model predicted the concentration of chlorophyll a would reduce up to 3 µmg/L, with the 30% reduction of nitrogen loading. This program was continued with the second phase of TMDL, by setting the goal for Neuse Estuary to compliance with North Carolina chlorophyll a at 40µg/L (Stow et al., 2003). Phase II of TMDL was evaluated by using the extensive monitoring and modelling program, Neuse River Estuary Modelling and Monitoring Project (ModMon) from 1996 to 2000 by using CE-QUAL-W2 and Bayesian probability network model (Stow et al., 2003).

After a decade of TMDL implementation plan in Neuse River Estuary, a post-monitoring study was conducted to monitor the 30% of nitrogen reduction has been achieved or not (Alameddine et al., 2011). By using the Bayesian model, the TMDL implementation plan has achieved 32% of nitrogen reduction at Neuse River Estuary by using wastewater treatment plan as the major point sources control. Based on the post-monitoring analysis, TMDL implementation plan at Neuse River Estuary was successful in reducing the pollution sources. Yet, the long-term monitoring program was one of the important keys to measuring the successfulness of the TMDL program (Stow et al., 2011).

Another important element in TMDL development was the involvement of stakeholder either internal or external. The high quality and positive impact of TMDL can be developed by having a good involvement and participation from the stakeholders (Cabrera-Stagno, 2007). The active involvement of stakeholders can give advantages to data collection for analysis, model development, and reduce error during TMDL development (Gaddis et al., 2010). The great involvement from the stakeholders can ensure the development and implementation process of TMDL can be successfully done.

The TMDL approach in Malaysia need to caution for few problems according to the 50 USEPA approved TMDL or delisting documents at few states (Keller & Cavallaro, 2008). There were few factors that need to be taken into account when developing TMDL such as (1) the method of water quality data collection should be uniform, and clearly defined, the time period of the data used is not too long (it is suggested that data should not be more than 5 years), (2) ensure the TMDL was necessarily developed for the waterbody, (3) the pollution loading allocation and monitoring strategy should be properly identified, and lastly (4) strong justification for delisting from 303(d) list (Keller & Cavallaro, 2008). Since the development of TMDL required much effort and cost, the appropriate techniques were important to meet TMDL goals (Stringfellow, 2008).

2.2.2 TMDL implementation plan in Asia

TMDL has been studied in few Asia countries such as Thailand, China, Taiwan, and South Korea. The implementation of TMDL was important to restore the impaired watershed in the Asia regions. The implementation of TMDL in Asia countries can be referred for TMDL implementation in Malaysia. In China, TMDL has been developed to restore the water quality at Lake Dianchi, China (Wang et al., 2013). The restoration of Lake Dianchi has taken place over 20 years ago, with no significant improvement. Therefore, TMDL was developed, together with decision support system analysis by using EFDC model to analyse various load reduction scenarios for the cause and effect relationship between loadings and in-lake eutrophication condition, since the China central and local governments were allocated with more funding for 5 years, to restore the water quality in Lake Dianchi. They found out approximately 80% loading reduction needed to achieve complete compliance at Class III.

The development of TMDL in China has evolved with the development of integrated environmental decision support system (EDSS) for water pollution control, integrated with TMDL at Beiyun River, China (Zhang et al., 2015). A study by Zhang et al. (2015) claimed that the integration of EDSS with TMDL, helped in determining the water quality goals, simulated the water quality and water environment capacity, and established appropriate pollution control measures through scenario simulation. In 2012, the study done by Zhao et al. demonstrated the load reduction was needed by using EFDC water quality model for TMDL approach, in order to make sure the water quality of Lake Fuxian in Class I water quality standard. The result shows two scenarios have been created; scenario one indicated that the loading of TN, TP, and COD should be reduced by 66%, 68%, and 57%, respectively, where they considered the lake water quality over the future development of lake. While scenario two showed that if they only considered annual average surface water concentration, then, the further increase of watershed-loading is still possible without violating the water quality standard.

In Thailand, the TMDL has been developed using MIKE II model at Thachin River, Thailand, to determine the water condition of biochemical oxygen demand (BOD) (Singkran, 2010). The study shows that, in order to keep the BOD concentrations within the water quality standard along the Thachin River across the seasons, the BOD load need to be reduced from the specific sources such as swine farms, aquaculture, urban communities and industry. Unfortunately, they realized that to reduce the huge amount of BOD, and this might be difficult for few reasons such as no implementation of strong regulations for controlling point sources, insufficient local wastewater treatment plan and low efficiency of wastewater collection, and treatment process. Therefore, to ensure the implementation of TMDL in Melaka River was successful, the involvement of all stakeholders was important.

South Korea was one of Asia countries that have been developing TMDL, to improve the TMDL management system, which has been regulated by Korean Ministry of Environment, since 2004 (Lee et al., 2013). The TMDL was introduced to the four major rivers in Korea, which was Nakdong River, Geum River, and Yeongsan River compulsory to develop TMDL, whereas Han River has conducted the TMDL voluntarily (Poo et al., 2007). Previously, Korea has focused on BOD parameter for pollution reduction during the first stage of TMDL implementation (2004-2010), however the strong backlash from local government cause the Total Phosphorus (TP) as additional target water quality parameter to be studied in the second stage of TMDL implementation (2011-2015) (Lee et al., 2013; Kim et al., 2016).

Lee et al. (2013) suggested to used TANK model to stimulate daily stream flows, and 7-parameter log-liner combined with the minimum variance unbiased estimator, and specific load duration curve, in order to set the proper target water quality for TMDL, and to find alternative to set target water quality for all flow condition regardless the wet periods and dry periods. The study found out that the target water quality parameter and the general water quality status of water quality management can be determined by using load duration curve analysis. This result was supported with a study by Kim et al. (2012), who has developed a web-based load duration curve system as effective tools for estimating TMDL since it can estimate TMDL quickly with limited resources.

Kim et al. (2016) studied the effect of TMDL implementation at the Geum River, Korea, which divided the analysis into a four-time section, which was Pre-TMDL stage (2003-2005), the early first-stage TMDL (2006-2008), and the late first-stage TMDL (2009-2010), the second-stage TMDL (2010-2012). According to the study, the improvement does not appear in the early first-stage, but the improvement shows at the tributary's river (Gap Stream and Miho Stream) in the late first stage of TMDL. While, at the mainstream, the effect of water quality improvement only showed during the second stage of TMDL. The study showed that the TMDL implementation has a significant improvement in BOD concentration, with the assessment on the implementation was conducted annually.

In Taiwan, a study at Fei-Tsui Reservoir, the most important water for drinking sources, has been contaminated with nonpoint sources pollution (Hsieh & Yang, 2006). The TMDL was developed by using BASIN model to allocate the nonpoint sources pollution, and the Vollenweider Model was used to allocate for point sources pollution. According to the study, the reduction of 50% phosphorus loading was needed, using Best Management Practices (BMPs) strategies. Many TMDL implementation plan was developed in Asia countries, which become important information for development in Malaysia. This experience from other countries would give benefits for TMDL development in Malaysia, with greater successfulness of pollution control program.

Up to the date this research was conducted in 2013, there was no study on TMDL implementation or approaches has been done in Malaysia. This research was conducted to determine the potential for development of a TMDL implementation plan in Malaysia. According to the report from DOE in 2015, the first TMDL implementation plan has been proposed in the 11th Malaysia Plan (Rahman, 2015). TMDL has become one of the future approaches to be implemented in Malaysia (Ithnin, 2015) Besides, there was suggestion for TMDL approaches in Malaysia done by the Institute of Engineering Malaysia (IEM), according to the position paper on water quality and environment, in order to preserve the water quality of the river. Therefore, this study was important to determine the applicability of the TMDL approach to be implemented in Malaysia, especially at the Melaka River.

2.2.3 Melaka River as a selected study area for TMDL approach

From the mouth of the Straits of Melaka to the Kg. Gadek, the length of the Melaka River is over 40.0 km. The river basin area was 615 km^2 and consists of oil palm, rubber, urbanization, forest, garden mix, open areas, lakes/ponds. The Melaka watershed includes the area of Alor Gajah, Melaka Tengah, and east of Jasin (DOE, 2004; Department of Irrigation and Drainage [DID], 2008). In general, the topography of the study area consists of coastal plains and inland. The study area consists of uniform climate with high moisture and heavy rain, with their main monsoon was southeast and northeast monsoons (Jabatan Pengairan dan Saliran [JPS], 2008). During the southwest monsoon season, the study area receives little rainfall as protected by Sumatra. On average, the rainfall in the area was about 2000 mm per year (JPS, 2008). The Melaka River was located in the district of Alor Gajah and Melaka Tengah as shown in Figure 2.2.

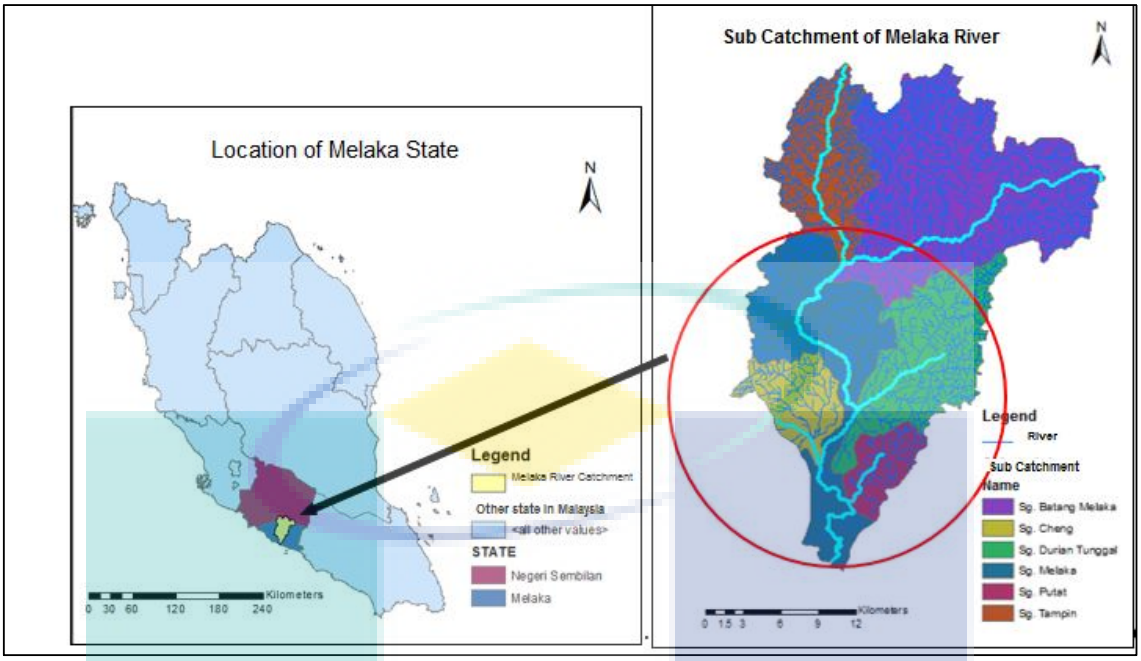


Figure 2.2 Location of the Melaka River.

There were a lot of tributaries contribute to the Melaka watershed, with five main rivers which were Batang Melaka River, Tampin River, Melaka River, Durian Tunggal River, Cheng River, and Putat River (DOE, 2004). There were three main tributaries that contribute to the main river which were Durian Tunggal River, Cheng River, and Putat River. All three tributaries rivers were flowing into the Melaka River and contribute to the inclusion of higher pollutant loadings into the main river (Rosli et al., 2015). Melaka River has been listed as a historical and heritage site by UNESCO in July 2008 that become the main attraction for tourism activities (Hua, 2015; Gunasekaran et al., 2015). Based on the water quality monitoring data conducted by the DOE on the year 2011 to 2016, the water quality status of the Melaka River was in Class III, particularly near the river downstream of Melaka City (DOE, 2016). While the report from DOE Melaka State (2017) as shown in Table 2.2, shows the trend of Melaka River WQI, the decrease in the water quality of Melaka River from Class II in 2015, into Class III in 2016 and 2017. This shows that the water quality of the Melaka River has no improvement and decrease from 2016 to 2017.

Table 2.2 Classification of WQI for Melaka River Watershed at Melaka from 2015-2017.

Watershed	Water Quality Index (WQI)								
	2015	Class	Status	2016	Class	Status	2017	Class	Status
Linggi River	82.99	II	C	83.70	II	C	73	III	SP
Kesang River	80.89	II	SP	75.80	III	SP	78	II	SP
Melaka River	76.94	II	SP	74.50	III	SP	69	III	SP
Duyong River	74.56	III	SP	69.50	III	SP	53	III	P
Merlimau River	63.89	III	SP	59.50	III	SP	56	III	P
Sri Melaka River	58.03	III	P	58.0	III	P	79	II	SP

*C= Clean; SP= Slightly Polluted; P= Polluted

Sources: DOE Melaka States, (2017)

Recently, Melaka River was often associated with environmental pollution problems resulting in outstanding issues such as the death of the fish and smelly river. The hundreds of wild marine and freshwater fishes have been found dead and floating in Melaka River on 22 April 2014, due to the low of oxygens, while the local tourist guide and fishermen claim the incidence happened several times in a few years ago (Pau et al., 2017). According to Hua & Marsuki (2014), Melaka River has experienced bad smell produced by the river, due to the gas released into the air during the hot weather, which gives the negative impact to Melaka citizen. This condition has been proved by the study of Rosli et al. (2015), the downstream part of Melaka River was classified as highly polluted sites (HPS), and the river appeared darker brown and smelly, due to the high population density and rapid development activities. According to Hua (2015), the quantitative study using questionnaire proved the feedback from the respondent who stays near to the river, claiming that the rapid development is the main factor to cause water pollution to occur and contributing negative impacts to the human and ecosystems. The main sources of pollution were identified from the sewage, domestic waste from commercial and residential areas, waste from wet markets and industries. In addition, the sources of nonpoint pollution were from the agricultural, construction, and municipal areas. Rapid development and the increase of population, without the presence of a specific monitoring system and planning strategies for the preservation of the river led to the decline in the water quality. The extensive development project along the river also affected the river water quality (Pau et al., 2017).

Based on observations during the water quality sampling conducted from August 2014 until October 2014, there were several factors contributing to the deterioration of water quality at the Melaka River, such as, the water retention activities to maintaining the water level for boating activities purpose and tourism attraction at the downstream part of Melaka River. The water quality was deteriorated because it has been stored for seven days without proper water flow. Figure 2.3 taken downstream of the Melaka River show a lot of garbage was thrown into the river. While Figure 2.4 shows the boating activities along the Melaka River, and the river appeared to be in a darker colour.

Figure 2.3 A lot of garbage was thrown into the Melaka River. The picture was taken during the sampling on October 2014.

Figure 2.4 River cruise activities along the Melaka River, and the dark colour of the river. The picture was taken during the sampling on August 2014.

The Natural Resources and Environmental Ministry (NRE) has allocated RM285 millions for the second phase of the rehabilitation and beautification of Melaka River project which was expected to give significant changes into the water quality of the river from Class III to Class IIB in 2014 (Murali, 2013). However, the water quality of Melaka River, according to DOE water quality report, the Melaka River had achieved Class II in 2014, but the quality dropped back in Class III in 2015-2016. This condition may happen due to the increase of 50% of tourist expected from the rehabilitation and beautification of Melaka River project (Murali, 2013). This condition has encouraged this research to be conducted to restore water quality at the river and preserve the Melaka River as historical and heritage property. In the effort to restore the water quality, the of TMDL implementation plan approach was carried out to identify the major contributors of the pollution to the river and strategies to reduce the sources of pollutants into the river.

2.3 Water quality model as planning tools for TMDL

In the TMDL approach, there were few methods that can be used to determine the allocation of pollutant loads, such as mass balance equation, load duration curve, and water quality model (Petersen et al., 2008). This research has emphasized the application of water quality model as planning tools for pollutant loads allocation. Water quality model was used to predict and describe the water quality condition in the river system to make sure the water quality aims will be maintained under a wide variety of conditions (Wang et al., 2013). Therefore, in the TMDL implementation plan approach, the water quality model was used to allocate the WLA, LA, and MOS for pollutant reduction of the river (Wang & Bi, 2016).

The applications of the water quality model have been used by developed countries since the early 1970s for water quality management. Basically, water quality model was able to predict changes in water quality parameter based on the changes in quality, discharge or location of a point or non-point input sources, as an integral part during the TMDL approach (Salvai & Bezdan, 2008). The basic principles in model selection for TMDL program were the objective of management wants to achieve, a specific characteristic of the site that are parallel with management objectives, and available resources to support the modelling requirement (Zhao et al., 2012). By following these basic principles, the suitable water quality model for TMDL approach can be determined.

There were two types of water quality model, which is a stochastic and deterministic model, where both models can be empirical or theoretical or both (Mohamed, 2008). The empirical model relates to water quality parameter to specified output on the basis of past-observed empirical relationship, while the theoretical model tries to represent it mathematically by physical, biological and chemical processed that affecting each water quality parameter (Boyacioglu & Alpaslan, 2008). The deterministic model basically attempts to simulate natural processes of self-purification in river system with each process modelled mathematically using derived parameter and rate constant, and able to forecast unique result from the specified set of input condition without any consideration of the true relationship between input and predicted result (Whitehead, 2016). While, the stochastic model was trying to randomize error in the water quality model by using uncertainty analysis such as Monte Carlo methods (Whitehead, 2016). The development of a water quality model provides an effective decision-making technique that reliable and defensive for water quality management to solve the water quality problems.

QUAL2E model was developed by the United States Environmental Protection Agency (USEPA) for waste load allocation (WLA), discharge-permit allocation, and other pollution evaluation in the TMDL program (Mohamed, 2008). However, there were several limitations experienced by QUAL2E model such as the model was the best suited for point sources discharged, but unsuitable for the river that experience temporal variation or major discharges that fluctuate significantly over a diurnal period or even shorter time (Mohamed, 2008). Another limitation of QUAL2E model was the lack of provision for conversion of algal death to BOD, which was an autochthonous source of organic matter, where it is important for algal bloom phenomenon. The maximum numbers of reaches, computational element, and junctions are also limited in this model. Therefore, the model cannot simulate a larger river basin with high accuracy (Palmieri & Carvalho, 2006).

Environmental Fluid Dynamic Codes (EFDC) was a 3D-hydrodynamic and complex water quality models, which is recognized as multitasking water quality models, can be used to simulate flow, transport, and biogeochemical process either in surface water, including rivers, lakes, estuaries, reservoirs and wetlands (Zhou et al., 2014). The main function of EFDC were hydrodynamics, water-quality eutrophication, and sediment toxic contaminant transport systems (Jeong et al., 2010). According to Kannel et al. (2007), the complex water quality model such as 2-D and 3-D model can show the actual situation of the river.

While the study done by Wang et al. (2013), used 3-D modelling approach to predict the load reduction for TMDL. Through the process of calibration and validation of the model, it shows the model performs well in reproducing the observed spatial pattern and temporal trends in water quality. There were three TMDL scenarios created that require different load reduction, which was 80%, 66%, and 54%, in order to achieved class III, IV and V, respectively, as their desired water quality target. Based on the scenarios created, the model was applied to conduct a series of scenario analysis by simulating on how the in-lake algal bloom intensity will respond to different load reduction patterns. The result obtained from the water quality model will guide the decision makers to make effective management in future.

A model of water quality analysis, the mathematical model was used worldwide for the evaluation of surface water quality should not consist of mathematical analysis and accurate implementation only, but also a precise determination of the most sensitive model parameters was necessary for reliable prediction of the water quality model. The two processes involve determining the confidence in the model simulation was the calibration and validation process. The calibration process was a process of adjusting or "tuning" the parameter values to obtain an optimal agreement between the simulated observed data (Salvai & Bezdan, 2008). During model calibration, numerical values for each parameter, state variable initial condition, and boundary condition, must be supplied to the model (Mohamed, 2008).

The TMDL analysis required the identification of MOS for consideration of variability and uncertainty during the development process (Chung et al., 2011). The variability refers to temporal and/or spatial variation in water quality conditions that affect the management goal, while uncertainty refers to random prediction error resulting from a limitation in data and model used to achieve the allocated loads (Foraste et al., 2006). MOS can be achieved by using implicit or explicit approaches (Wang & Bi, 2016). The implicit approach includes the MOS using the conservative model assumption for allocation, whereas the explicit approach reserves a portion of total TMDL for the MOS (Chung et al., 2011). MOS was important to allocate during TMDL development, to avoid the program from being overdesign or under design.

In this study, the water quality model has been developed by using InfoWorks RS version 10.5. This model has been widely used in Malaysia for water quality analysis and gives advantages in developing the TMDL, as the model were reliable and convenient to be used. The study of water quality model by using InfoWorks (RS) was well established and well known in Malaysia (Mah et al., 2007; Toriman et al., 2011; Toriman et al., 2010). Since TMDL implementation was still new in Malaysia, it was better to start with a simple model compatible with available resources and increase the complexity along with problem demands and the available resources provided (Kim et al., 2012).

The water quality model InfoWorks (RS) was one-dimensional hydrodynamic simulation program by solving the fully dynamic de Saint-Venant equations developed by the Wallingford, the United Kingdom, capable of performing steady and unsteady flow water surface profile calculations (Ghani et al., 2010; Toriman et al., 2010). The governing equation in for InfoWorks RS was shown in equation 2.1 (Ramli et al., 2011):

1-D continuity equation;

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad 2.1$$

The basic equation is used by the model to compute the flows, depths, and discharges as shown in the equation above (Ramli et al., 2011). There were few assumptions for Saint Venant Equations, where the flow was one-dimensional, the hydrostatic pressure prevails, and vertical accelerations were negligible, the streamline curvature was small, the bottom slope of the channel was small, the Manning's equation was used to describe resistance effects, and the fluid was incompressible (Ramli et al., 2011). InfoWorks Water Quality was a computer program used to model water quality in open channels. The model has two separate simulation engines, which is a hydraulic engine and water quality engine as shown in Figure 2.5. The hydraulic engine provides the hydrodynamic data, which are used in the water quality simulation. The hydraulic model consists of network data, where the physical component does not change with time, whereas the hydrological model was part of the event data such as initial condition, boundary condition, and simple control data. The model used a finite differences approximation to the advection-diffusion equation, where the SMART algorithm develops by (Gaskel & Lau, 1988), were used to approximate the advection term. This model consists of three main characteristics which are network, event, and water quality.

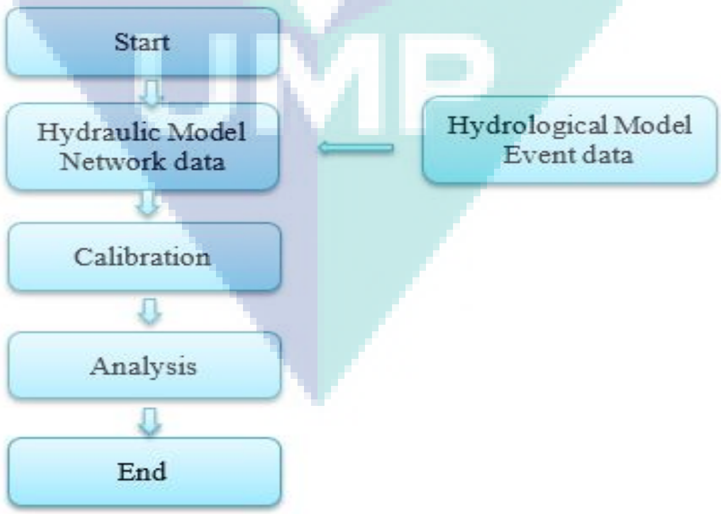


Figure 2.5 Model of the development process for water quality modelling using InfoWorks (RS).

The Infoworks RS has also been well adapted for generating flood map in Malaysia such study by Mah et al. (2007) and Hii et al. (2009) generated the flood map at Sarawak River Basin. Ghani et al. (2010) have established the InfoWorks RS at Muda River to study the long-term behaviour of the river, and the risks of flooding event to occurs. By using this water quality modelling, the information on the variation of river water levels, discharges, and velocities during flood events can be attained. Also, another study by Ghani et al. (2016), they used 1D and 1D-2D coupled hydrodynamic model InfoWorks RS to simulate the inter-related changes in channel-bed profile, width variation and changes in bed to develop a digital map of flood inundation areas at Sungai Pahang for the year 2014. This study showed the comparison of changes in cross sections aggradation and degradation, flood delineation and inundation area with and without sediment transport modelling.

Besides, InfoWorks RS model has been used at Juru River, to study the types of pollution and the tidal influences on river water quality (Toriman et al., 2011). Sabri et al. (2014), has done study at Gombak River, to see the relationship between BOD and AN and river flow at three different types of land use which is a forested, semi-urban, and urban area by using InfoWorks RS modelling. The modelling was used to generate flow from the various catchment and cross sections and produce the predicted discharge flow at the interested area. Most of InfoWorks RS application in Malaysia was used to study the flooding event implication. Therefore, in this study, the application of the well-known InfoWorks RS water quality model has been extended for the development of a TMDL implementation plan in Malaysia.

2.4 Overview of physicochemical parameters of water quality

There were several water quality parameters usually used to indicate the health of water such as DO, BOD, COD, inorganic nutrient, conductivity, salinity, total suspended solids (TSS), temperature and pH were important in determining the water quality of river (Mustapha et al., 2013). Besides, the population of aquatic species such as zooplankton and phytoplankton also depended on nutrient availability, light intensity, water temperature and pollution occur (Bailey & Ahmadi, 2014). In this study, the water quality parameters were important in determining the water quality standard for TMDL target, WQI analysis and Pearson Correlation analysis. Each parameter describes its own properties and characteristic in the determination of water quality standard for the river.

DO was representing the amount of molecular oxygen dissolved in water, found in microscopic bubbles of oxygen that was mixed in the water and occur between water molecules (Othman et al., 2012). DO was an important indicator of a water body's ability to support aquatic life (Mohamed et al., 2015). The most common parameter in observing the water quality, with the minimum DO concentration was 2 mg/L to maintain higher life form, and 4-5 mg/L to survive natural stream. If more oxygen was consumed than produced, DO levels will decline, and some sensitive animals may move away, weaken, or die.

There were many factors that can affect DO level such as the volume and velocity of water flowing in the water body where usually in fast-moving streams, flowing water was aerated by bubbles and if unpolluted, it is usually saturated with oxygen (Sheila, 2007). Suratman et al. (2016), showed the degradation of DO at Setiu Wetland, Terengganu was due to several factors such as fertilizer runoff from the large scales of palm oil plantation activity at the upstream, domestic input from the town, and excess food from fish farming activities. These findings were supported by a study from Kellner and Hubbart (2017), the DO values were affected by many factors of natural an anthropogenic source such as streamflow, land use and water temperature and pressure.

A measure on the amount of oxygen that bacteria will feed while decomposing organic matter under aerobic conditions was also known as BOD (Mohamed et al., 2015). The BOD can be simplified as the biodegradable fraction of the potential DO consumption of water (Othman et al., 2012; Aris et al., 2013). In the aquatic environment, the organic matter was decomposed, and fed by the microorganism such as fungi and bacteria. In order to feed upon this decaying material, they need some amount of oxygen to oxidize organic waste under the aerobic condition that measured as BOD (Mohamed et al., 2015). It showed that the amount of oxygen required for the biological process either degradation or oxidation, which means the higher BOD value, indicating that the higher of oxygen depletes in the river (Othman & Elamin, 2014). Therefore, the BOD was inversely correlated with DO values in the river (Suratman et al., 2016).

COD is known as the measure of oxygen demand created by toxic organic and inorganic compound, and biodegradable substances (Waziri & Ogugbuaja, 2010). The higher concentration of COD was contributed by animal waste and death plant (Rwoo et al., 2016). The COD was found as one of a significant pollutant that contributes to the water pollution in the previous study at Langkawi Geopark (Aris et al., 2013). There was a significant relationship between DO, BOD, and COD parameter, where the value of DO depend on the value of BOD, based on the decomposition activity, while COD was part of BOD value (Mustapha et al., 2013). The COD can determine the number of organic pollutants present in the surface water or wastewater, which was found to be a useful measure on the water quality (Mohamed et al., 2015).

Phosphorus is a nutrient found in all living things and divided into several forms. Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate (USEPA, 2012). The finding from Abdollahi et al. (2017) study, show the changes of river colour into green during the hot and dry season due to the high amount of phosphate and other substances has increased the rate of algae, which leads into pollution. However, an abundance of algae can increase the decomposition activities, and the greater amount of oxygen was used by decomposer, can cause depletion of oxygen (Abdollahi et al., 2017). There were many sources contribute to the higher level of phosphorus in the river such as human and animal wastes, industrial waste, runoff and erosion, fertilizer, soil and rocks, wastewater treatment plants and commercial cleaning preparations (Ibrahim et al., 2014). According to a study by Kozaki et al. (2017), the total phosphorus has a higher correlation with COD, may due to pollution from incomplete or untreated raw sewage water.

Nitrogen is one of the essential nutrients in the aquatic ecosystem after carbon, oxygen and hydrogen. The nitrogen pollution has been increased for the past few decades ago, caused by the increase from anthropogenic source, one of the important sources of nitrogen to the marine ecosystem. The human activities such as sewage discharge, the agricultural runoff with high usage of nitrogen fertilizer (Caffrey et al., 2007; Ibrahim et al., 2014; Sharif et al., 2015), and industrial waste including the textile printing, dyeing and paper industry were the sources of excess nitrogen in coastal water, which then contribute to the eutrophication and harmful algal bloom event to be occurred (Spokes & Jickells, 2005; Bu et al., 2011). The higher level of nitrogen in the water column will result in the negative environmental effect (Bailey & Ahmadi, 2014). Besides, the high rainfall intensity may cause soil and nutrients were exposed to erosion and increase the nutrient loading (Sharif et al., 2015). The inorganic nitrogen such as nitrate (NO_3^-) and ammonium (NH_4^+) was closely related to the DO under the aerobic and anaerobic condition (Kozaki et al., 2017). While Abdollahi et al. (2017), in their study found that the nitrate concentration was higher during low flow period with the main contributor was from farmlands and N-P-K fertilizer used in agricultural activities.

The temperature in the river was a measure of how much heat present in the water, which affects the rate of metabolic and reproductive activities in organisms (Uqab et al., 2017). The water quality of a river can be affected by temperature in some conditions such as the amount of dissolved oxygen in the water, which the cold water has higher oxygen compared to warm water (Matta et al., 2017). The intrusion of anthropogenic sources into the river such as the discharge of wastewater can increase the temperature of the river (Uqab et al., 2017). The high temperature during the dry season, can worse water quality conditions due to the reduction of DO concentrations and increase the number of pollutants (Sharif et al., 2015). The previous study showed the temperature was high during the low flow period, and low temperature during the high flow period (Abdollahi et al., 2017).

The pH is known as a measure of the hydrogen ion concentration (Uqab et al., 2017), where it can represent the effective concentration of hydrogen ions (H^+) in water (Widyastuti & Haryono, 2016). The pH scale ranges from 0 to 14, where the pH of 7.0 indicates a neutral solution, pH values smaller than 7.0 indicate acidity, pH values larger than 7.0 indicate alkalinity. There were few factors that influenced the pH in water such as high inputs of freshwater caused the lower value of pH, the mixing process of freshwater and seawater has increased the pH value, and the influence from anthropogenic sources causes the water more acidic in pH (Suratman et al., 2016).

2.5 Pearson Correlation Coefficient analysis

Pearson correlation coefficient is used to measure the relationship between two variables for predicting each other, also determine variables correlation intensity, relativity and direction (Prematunga, 2012; Sensuse et al., 2015). The coefficient of determination is given by the square of the Pearson correlation coefficient which varies from greater than -1, and smaller than 1, which showed the relationship bet, two variables (Prematunga, 2012). It describes the proportion of variance in the outcome variable which can be explained by the variance in the predictor variable (Prematunga, 2012). Therefore, the estimation of Pearson correlation in the present study was to find the possible relations between water quality parameters (Sharma et al., 2014). The Pearson correlation coefficient can be done by using the statistical analysis software, SPSS. SPSS program as the statistical software support makes the simple correlation between variables can be achieved (Sebjan & Tominc, 2015).

2.6 Water quality index (WQI)

In Malaysia, the water quality benchmarking system has been widely used to estimate the river water quality status, the water quality index (WQI) analysis. In other countries, various water quality assessments were used to analyse the water quality of the river. For instance, water quality criteria were analysed based on the General Quality Assessment (GQA), of which the latter possesses a separate measurement for chemical and biological water quality in England, Wales, and Northern Ireland (Tucker, 2010). The chemical water quality was based on the level of DO, BOD, and NH_3-N, while biological water quality was based on the numbers of macro-invertebrates.

The water quality of the river was determined based on the relationship between water quality impairment, the pollutants and process involved. Based on the water quality parameter available, the status of river water quality was obtained using the WQI system. The WQI system was already developed since the 1960s (Sutadian et al., 2016). The purpose of implementing WQI system was to simplify the numerous water quality parameter data into the simplest decimal number that present the water quality status of the river (Othman et al., 2012; Effendi, 2016).

The WQI can be developed either for a general assessment of river status or for determining the specific purpose of the river. According to the reviewer on the development of river WQI by Sutadian et al. (2016), there were more than 30 types of WQI were available and used around the world. However, there were 7 types of WQI that were widely used and most popular, as listed in Table 2.3. Based on the study, they found out the WQI was useful (1) to provide an overall status of water quality to authorities and community, (2) to study the impact of regulatory policies and environmental programs on environmental quality, (3) to compare the water quality at different sources and sites, and most important was (4) to assist decision makers and public to make the decision (Sutadian et al., 2016; Effendi, 2016). The comparison should be made cautiously as each country possesses different climate and socioeconomic conditions, and river.

Table 2.3 List of mostly used WQI around the world.

Name of WQI	Selected parameters	Country applied
Canadian Council of Ministers of the Environment (CCME) Water Quality Index	At least 4 parameters Maximum number of parameters was not specified	All states in Canada, one state in India, Albania, Chile, Egypt, Iran, Spain, Turkey, Poland
National Sanitation Foundation (NSF) Index	11 parameters: DO, faecal coliform (FC), pH, biochemical oxygen demand—5 days (BOD_5), temperature, TP, NO_3, turbidity, total solids (TS), pesticides and toxic compounds	USA, Brazil, India, Iran
Oregon Index	6 parameters (first version): DO, pH, FC, BOD_5, TS, NO_3, NH_3-N 8 parameters (second version): TP, temperature (in addition to the 6 parameters in the first version)	USA
Bascarón index	26 parameters: pH, BOD_5, DO, temperature, total coliform (TC), colour, turbidity, permanganate reduction, detergents, hardness, DO, pesticides, oil and grease, sulphates (SO_4), NO_3, cyanides, sodium, free CO_2, chloride (Cl), NH_3-N, conductivity, magnesium (Mg), phosphorus (P), nitrites (NO_2), calcium (Ca) and apparent aspect	Spain Argentina Brazil Korea India
House's Index	9 parameters for general water quality: DO, NH_3-N, BOD_5, suspended solids (SS), NO_3, pH, temperature, Chlorides (Cl), and Total Coliform (TC) 13 parameters for potable water supply: DO, NH_3-N, BOD_5, SS, NO_3, pH, temperature, Cl, TC, SO_4, fluorides, colour and dissolved iron 12 parameters for aquatic toxicity: dissolved copper, total zinc, dissolved cadmium, dissolved lead, dissolved chromium, total arsenic, total mercury, total cyanide, phenols, total hydrocarbons, polyaromatic hydrocarbon PAHs, total pesticides 12 parameters for potable sapidity: total copper, total zinc, total cadmium, total lead, total chromium, total arsenic, total mercury, total cyanide	UK, Spain
Scottish Research Development Department (SRDD) index	10 parameters: DO, BOD_5, free and saline ammonia, pH, total oxidized (TO), N, phosphate, SS, temperature, conductivity and Escherichia coli (EC)	Scotland, Spain, Portugal, Thailand, Iran
Fuzzy-based indices	No guidelines	Spain Iran India Brazil

Source: Sutadian et al. (2016). Reprinted with permission.

In Malaysia, the DOE developed the WQI system in 1974 (Low et al., 2016) to analyse the trends in water quality of rivers based on six parameters as the indicator, which were DO, BOD, COD, pH, NH_3-N, TSS (Ismail et al., 2016). The river can also be classified into five groups which were Class I, Class II, Class III, Class IV or Class V, to determine the level of pollution of the river. The Class I river was classified as clean, and suitable for conservation of natural environment, water supply with no treatment necessary, and fisheries activities for very sensitive aquatic species (WEPA, 2006; Ismail et al., 2016). While Class II can be divided into Class IIA, which suitable for water supply with conventional treatment, and fisheries activities for sensitive aquatic species (WEPA, 2006; Ismail et al., 2016). The Class IIB was suitable for recreational activities with body contact (WEPA, 2006; Ismail et al., 2016). The Class III of the river was suitable for water supply with extensive treatment required, and fisheries activities for common of economic value and tolerant species, also livestock drinking (WEPA, 2006; Ismail et al., 2016). While Class IV only suitable for irrigation, and Class V was not suitable for any activities above (WEPA, 2006; Ismail et al., 2016). The WQI classification based on the water quality parameters were given in Table 2.4, each parameter was categorised according to the WQI value into three groups which were clean, slightly polluted, and polluted as shown in Table 2.5 by using DOE standard.

Table 2.4 Water Quality Index Classification

Parameter	**Unit**	**Class**				
		I	**II**	**III**	**IV**	**V**
Ammoniacal Nitrogen	mg/L	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
Biochemical Oxygen Demand	mg/L	< 1	1 - 3	3 - 6	6 - 12	> 12
Chemical Oxygen Demand	mg/L	< 10	10 - 25	25 - 50	50 - 100	> 100
Dissolved Oxygen	mg/L	> 7	5 - 7	3 - 5	1 - 3	< 1
pH	-	> 7	6 - 7	5 - 6	< 5	> 5
Total Suspended Solid	mg/L	< 25	25 - 50	50 - 150	150 - 300	> 300
Water Quality Index (WQI)	-	< 92.7	76.5 - 92.7	51.9 - 76.5	31.0 - 51.9	> 31.0

Source: WEPA (2006); Ismail et al. (2016)

Table 2.5 Water Quality Classification Based on Water Quality Index

Sub index & water quality index	Index range		
	Clean	**Slightly polluted**	**Polluted**
Biochemical Oxygen Demand (BOD)	91 – 100	80 - 90	0 - 79
Ammoniacal Nitrogen (NH_3-N)	92 – 100	71 - 91	0 - 70
Suspended Solids (SS)	76 – 100	70 - 75	0 - 69
Water Quality Index (WQI)	81 – 100	60 - 80	0 - 59

Source: WEPA (2006); Ismail et al. (2016)

WQI was basically used to measure the water quality level that can be categorized into five classes as shown in the table above. Besides, WQI also can be used to make a comparison between different sampling points of a river or between different watersheds. There were many types of research conducted to evaluate the status of river water quality in Malaysia by using the WQI benchmarking system. The study was done by Zali et al. (2011) at Kinta River, Malaysia, used WQI for sensitivity analysis, and they found that the DO, SS and NH_3-N was the best parameter for WQI prediction, and suggested the reducing the parameter in WQI, can reduce the time and cost consuming, and more applicable for water resources management.

While, Azhar et al. (2015) claimed that, the WQI technique had reduced the variability in the target object, as the WQI methods used the supervised pattern recognition methods. On the other hands, study by Low et al. (2016), shows that the WQI was used to determine the water quality condition at rivers and ponds, such as the Timah Tasoh lake Perlis was classified in Class III due to high Manganese (Mn) pollution, and Kelana Jaya lakes were classified as Class V due to the pollution from overflow of untreated sewage oxidation ponds and high concentration of Cadmium (Cd) from the car wash and electroplating industries. The study done by Kasim et al. (2015) at Linggi River, Malaysia, showed the use of WQI to analyse the water quality status of the river, in terms of each parameter at different stations, and the WQI trend from 1997-2012 has been analysed.

In this study, WQI was used to determine the status of water quality at the Melaka River. According to the status achieved from the WQI analysis at Melaka River, the water quality model was developed to create scenarios for pollutant load reduction, for improving the river water quality based on the desired status. The WQI analysis was important in this study, to know the pollution status of the river and decided, at which the river's level should improve and achieve by doing the TMDL implementation plan. The TMDL at Melaka River has set up the desired water quality at Class IIB since Melaka River was involved in recreational and tourism activities.

2.7 Malaysia's current water quality status and watershed management program

Malaysia has various departments and agencies that play roles in the management of our river system. This has led to difficulties and disintegration in river management, whereby the status of the river was determined by a lot of government agencies at the state and federal level. The acts used in Malaysia to control the pollution of the river was Environmental Quality Acts 1974 (EQA) which applies to industrial discharge and waste only (Rahman, 2015). Another example of river management approach conducted in Malaysia was Integrated River Basin Management (IRBM), whereby the program aims to ensure clean and sufficient water, reduce the flood risk, and enhance environmental conservation. However, there were issues in the coordination of the agencies, and the states during the implementation of the approach (DID, 2010).

As there were no specific or distinct implementation and development measures of TMDL that has been regulated in Malaysia, it has huge potential to be developed and implemented. The development of TMDL is one of the most crucial parts in a river management plan, to ensure that the vision of Malaysia to become a developed country by 2020, will not negatively impact the water quality of the river. As economic development significantly gave impacts to the environment, as well as water health, therefore the demand for good water quality will increase concomitantly. Controlling the total maximum allowable pollution load into the river is another approach to ensure the desired river quality meets the designated uses. There were several programs done in order to manage the water resources in Malaysia, as shown in Table 2.6.

As Malaysia has undergone rapid development to achieve developed nation status by 2020, however, these rapid developments led to several environmental issues such as the degradation of river water quality. The water quality trend for a river basin in Malaysia for 2005-2016 was shown in Figure 2.6. The data provided by DOE (2017), showed the numbers of the clean river was reduced from 276 to 224 rivers in the latest finding during 2015-2016. Whereas, the numbers of the polluted river were increased from 33 to 46 river from 2015-2016. Even though multiple programs have been developed to manage the water resources in Malaysia, the numbers of polluted rivers are still increasing. Therefore, in this current work, the TMDL program has been studied and adapted to be suitable for Malaysia condition.

Table 2.6 List of available programs for managing water resources in Malaysia

Name of programmed	Responsibility	Lead Authority/ Collaborating Agencies
National River Register (2001) and Integrated River Basin Management (IRBM) Plan Studies on selected Basins	To develop a Register of Rivers in Malaysia, To recommend a list of River Basin 34 Transforming the Water Sector: National Integrated Water Resources Management Plan, Strategies and Road Map Management Units (RBMU) which defines the river basin boundaries for management purposes. To prepare IRBM plans for all 189 RBMU in the country. To develop a set of IRBM Blueprint Guidelines which gives the framework and methodology for the development of an IRBM plan To model TOR for IRBM planning	Natural Resources and Environment Ministry (NRE) and all State Governments
Urban Storm Water Management Manual (MSMA 2001)	A drainage design guideline published by DID Malaysia.	DID
"One State, One River" Plan 2002	A program to improve urban rivers environment through restoration and other improvement work.	Designated state exco

Table 2.6 Continued

Name of programmed	Responsibility	Lead Authority/ Collaborating Agencies
Implementation of IWRM Best Management Practices (BMPs) 2009	The implementation of eight mini projects spread over different states with the view of demonstrating BMPs in IWRM, focusing on a specific IWRM topic designed to promote awareness, capacity building, and public participation at the local level.	-
National Water Resources (NWR) Study 2011	The review and update data and information from an earlier study at Peninsular Malaysia, Sabah, and Sarawak.	DID
Klang River RoL Project 2012	To transform the Klang River into a vibrant and liveable waterfront with high economic value by 2020.	ETP
National Workshops and Fora on IWRM and IWRM Sub-themes	The colloquia, workshops, and seminars have been held as an effort for creating greater awareness, and capacity building on IWRM and related sub-themes.	-
Public Awareness Campaigns	To deal with issues related to both "water as a resource" and "water for livelihoods."	Government agency and NGOs

Table 2.6 Continued

Name of programmed	Responsibility	Lead Authority/ Collaborating Agencies
IWRM Capacity Building Initiatives and Programmes	The dissemination of IWRM to suit different target groups of stakeholders to improve their understanding of IWRM Enhanced IWRM through workshops, training of trainers, seminars either formally or informally.	-
National Water Resources Policy Action Plans (NWRP) (2013–2020)	To develop a National Water Resources Policy	NRE and DID
National Study for the Effective Implementation of Integrated Water Resources Management (IWRM) in Malaysia 2005	The study focused on awareness and advocacy, capacity building, best management practices and information architecture framework. The completed study report which comes in five volumes comprises a comprehensive set of guidelines, written for technical and professional levels covering various resource management-related topics, to assist in the implementation of IWRM in Malaysia.	

Source: Abdullah et al. (2016)

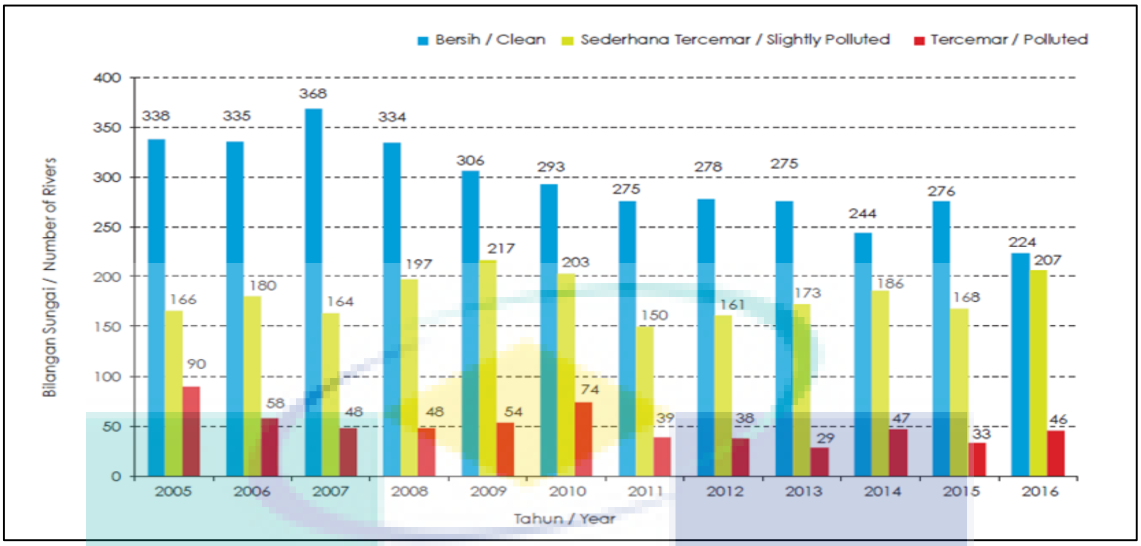


Figure 2.6 River water quality trend for 2005-2016.

Source: DOE (2017)

The TMDL implementation plan was initially developed with the identification of water quality problems. The degradation of river water quality has led the TMDL program to attain the deterioration of river. The TMDL program needs to recognise the poor river water quality that does not meet the water quality standard and create a list of it. Since TMDL has been successfully established in many regions, the experience and problems currently being faced by other nations will be good examples and models for Malaysia to test, implement and improvise to fit our requirement, in order to achieved Class IIB for Melaka River. Currently, Malaysia has formally adopted Integrated Water Resources Management (IWRM) as the way forward to sustainably manage its water resources.

Based on the 11th Malaysia Plan budget, the TMDL program was one of the solutions to water quality issues in Malaysia (Rahman, 2015). According to the news report, the minister from the Ministry of Natural Resources and Environment (NRE) says the DOE has been mandating to conduct a study of TMDL program in Malaysia, to improve the water quality, flood risks, ensuring the water supply and protect the environment (Chin, 2016; Moh, 2016). The TMDL in Malaysia still in the early stage and has a long way to go. This study examines the challenges during the development process and suggests several modification and integrations overcoming the limitations and problems that might be faced while implementing the TMDL in Malaysia's watershed.

2.8 Summary

This chapter was important to give the overall picture of the TMDL program, the implementation plan, and the current water resources program in Malaysia. The previous study shows how the TMDL program was developed in the United States and the implementation throughout the states. Besides, the TMDL in Asia countries such as South Korea, China, Thailand and Taiwan, were studied on how the implementation plan was done. The experienced from these countries can provide significant information and improvement needed during the TMDL development in Malaysia.

Furthermore, the important element in the TMDL approach is water quality model as the planning tools. Even though there were other methods to be used in TMDL but result from the previous studies has suggested that the water quality model was one of the best tools to be used in water quality management. By using a water quality model, the simulation for scenario analysis of water quality condition can be created, and the program for water quality improvement can be developed. Nowadays, there were many types of water quality model has been used to study the improvement can be achieved by the river. Some integration of modelling software was done to increase the capability of the water quality model during the analysis. The InfoWorks RS is one of well-established of water quality model in Malaysia; therefore, in this study, it was used during the water quality model analysis to provide a reliable database for further study in future. Another important element in TMDL was the determination of the desired water quality status need to be achieved by the river. The water quality index (WQI) has been widely used in Malaysia to determine the status of river water quality and classifying the river into classes. In other countries, a lot of types of assessment was done to study the health of the river. In comparison with other countries of WQI systems, the improvement can be done to Malaysia's WQI system by including more numbers of water quality parameter, since many pollution sources contributing to the water quality deterioration.

Therefore, in this study, there was a significant impact of water quality parameter and WQI analysis, for the TMDL approach. Besides, the determination of a suitable water quality model for the Melaka River, was crucial during this study to ensure the best planning tools were chosen to analyse the condition of the river. The review from the previous study has provided significant information for this study, as well as the improvement needed to achieve the desired results as been summarised in Table 2.7.

Table 2.7 Summary of the literature review on the water quality model and TMDL approach

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Zou et al. (2006)	To solve the excess nutrient levels at Wissahickon Creek basin of Pennsylvania.	The higher biological activities of excessive periphyton growth have led to the dissolved oxygen impairment.	Integrated hydrodynamic EFDC and water quality model, WASP/EUTRO	The 99% reduction of phosphorus has reduced the periphyton growth, and increase DO concentration.	TMDL at Melaka River to reduce COD pollutant loading by using InfoWork RS version 10.5 TMDL implementation plan at Melaka River: i. Point sources control by using wastewater treatment plant ii. Nonpoint sources control by using Best Management Practices (BMPs)

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Fakhraei et al. (2014)	To evaluate the chemical recovery in lakes ecosystem at Adirondack region of New York.	Provides a reliable option to recover the ecosystem and good prediction on the impact of future pollutant loading to the ecosystem.	Biogeochemical model (PnET-BGC)	There was a significant impact on controlling S deposition in recovering the lake's ecosystem, rather than controlling the N deposition.	
Bowen and Hieronymus (2003)	To solve high chlorophyll a and low dissolved oxygen concentrations at Neuse River Estuary of North Carolina.	This river has experienced dramatic fish kills.	CE-QUAL-W2 model	The concentration of chlorophyll predicted to reduce up to 3 μmg/L, with the 30% reduction of nitrogen loading.	

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Stow et al. (2003)	Setting a goal for chlorophyll a at 40µg/L for Neuse Estuary to compliance with North Carolina	It was the phase II of TMDL by using the extensive monitoring and modelling program	CE-QUAL-W2 and Bayesian probability network model	To address the problem of repeated violations of the ambient chlorophyll a criterion.	
Alameddine et al. (2011)	To monitor the 30% of nitrogen reduction has been achieved or not at Neuse River Estuary of North Carolina.	A post monitoring for TMDL implementation plan has been implemented for a decade	Bayesian model	TMDL implementation plan has achieved 32% of nitrogen reduction at Neuse River Estuary by using wastewater treatment plan as the major point sources control.	

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Wang et al. (2013)	To analyse various load reduction scenarios, and to explore the complex cause-and-effect relationship between watershed loadings and in-lake eutrophication condition.	The restoration of Lake Dianchi has taken place over 20 years ago, with no significant improvement.	EFDC water quality model.	It required approximately 80 % loading reduction, to achieve complete compliance at the highest target level (Class III)	
Zhang et al. (2015)	To simulate the water quality and water environment capacity and to establish appropriate pollution control measures using scenario simulations.	A comprehensive decision support tool specifically designed to facilitate TMDL development at the watershed-level	Integrated environmental decision support system (EDSS)	It provides researchers and managers with a simple but efficient tool to deal with variability and uncertainty issues in TMDL development with limited data requirements.	

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Zhao et al. (2012)	To develop a computational platform to quantify the cause-and-effect relationship between watershed loading and in-lake concentration of Lake Fuxian and calculate the TMDL for Lake Fuxian.	To reduce the pollutant loading of total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD) at the Lake Fuxian at China.	EFDC water quality model.	Two scenarios were identified as benchmarks for the total capacity control, provide a basis for bounding the future development and conservation activities in the watershed.	
Singkran (2010)	To determine the biochemical oxygen demand (BOD) at Thachin River, Thailand.	The BOD load needs to be reduced from the specific sources such as swine farms, aquaculture, urban communities and industry.	MIKE II model	It is difficult to reduce the huge amount of BOD for few reasons such as no implementation of strong regulations for controlling point sources, insufficient local wastewater treatment plan and low efficiency of wastewater collection, and treatment process.	

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Lee et al. (2013)	To stimulate daily stream flows, and 7-parameter log-liner combined with the minimum variance unbiased estimator, and specific load duration curve.	To set the proper target water quality for TMDL, at all flow condition regardless of the wet periods and dry periods.	TANK model	The target water quality parameter and the general water quality status of water quality management by using load duration curve analysis.	
Kim et al. (2012)	To develop a Web-based LDC system using Perl/CGI, GNUPLOT, JavaScript, and Google Maps API for the analysis of TMDL and water quality characteristics in a watershed.	To target appropriate watershed-specific BMPs.	Web-based load duration curve system.	Provides an effective tool for estimating the TMDLs, because it can estimate many TMDLs quickly with limited resources, compared with complex simulation models.	

Table 2.7 Continued

Author	Why is this study important?	The reason for this study to be done?	Methodology	Finding of study	Remarks
Kim et al. (2016)	To analyse the short-term and long-term change in water quality.	The effect of TMDL implementation at the Geum River of South Korea depending on its implementation stages.	Seasonal Mann–Kendall analysis, Kruskal–Wallis test, and Mann–Whitney test	The TMDL implementation has a significant improvement in BOD concentration.	
Hsieh & Yang (2006)	To allocate the nonpoint sources and point sources of pollution	The most important water for drinking sources has been contaminated with nonpoint sources pollution at Fei-Tsui Reservoir of Taiwan	BASIN model and Vollenweider Model	The reduction of 50% phosphorus loading was needed, using Best Management Practices (BMPs) strategies	

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter covers the methodology used including the procedure of sampling, water quality analysis, measuring the flow rate and the cross-section of the river water, statistical analysis, the water quality modelling analysis and the TMDL implementation approach. The methodology part can be divided into five sections, which are water quality assessment, statistical and WQI analysis, water quality modelling, allowable load allocation calculation and the TMDL implementation plan approach. The water quality assessment consists of a collection of data from water quality sampling and analysis, secondary data from government and private agencies such as the Department of Irrigation and Drainage (DID), Department of Environmental (DOE), and Department of Survey and Mapping (JUPEM). The information of water quality analysis was gathered from the laboratory analysis, was further used in statistical analysis and water quality index (WQI) analysis. All the procedure for laboratory analysis were referring to the American Public Health Assessment (APHA-4500, APHA-5210, APHA-5220) standard methodology. The methodology framework for the present work was summarized in Figure 3.1. The data collected from the water quality assessment were important to determine the environmental status of water resources and watershed management (Othman et al., 2012). Based on the water quality assessment, the most crucial water quality parameter to be improved by doing the TMDL approach was Chemical Oxygen Demand (COD) as the target parameter.

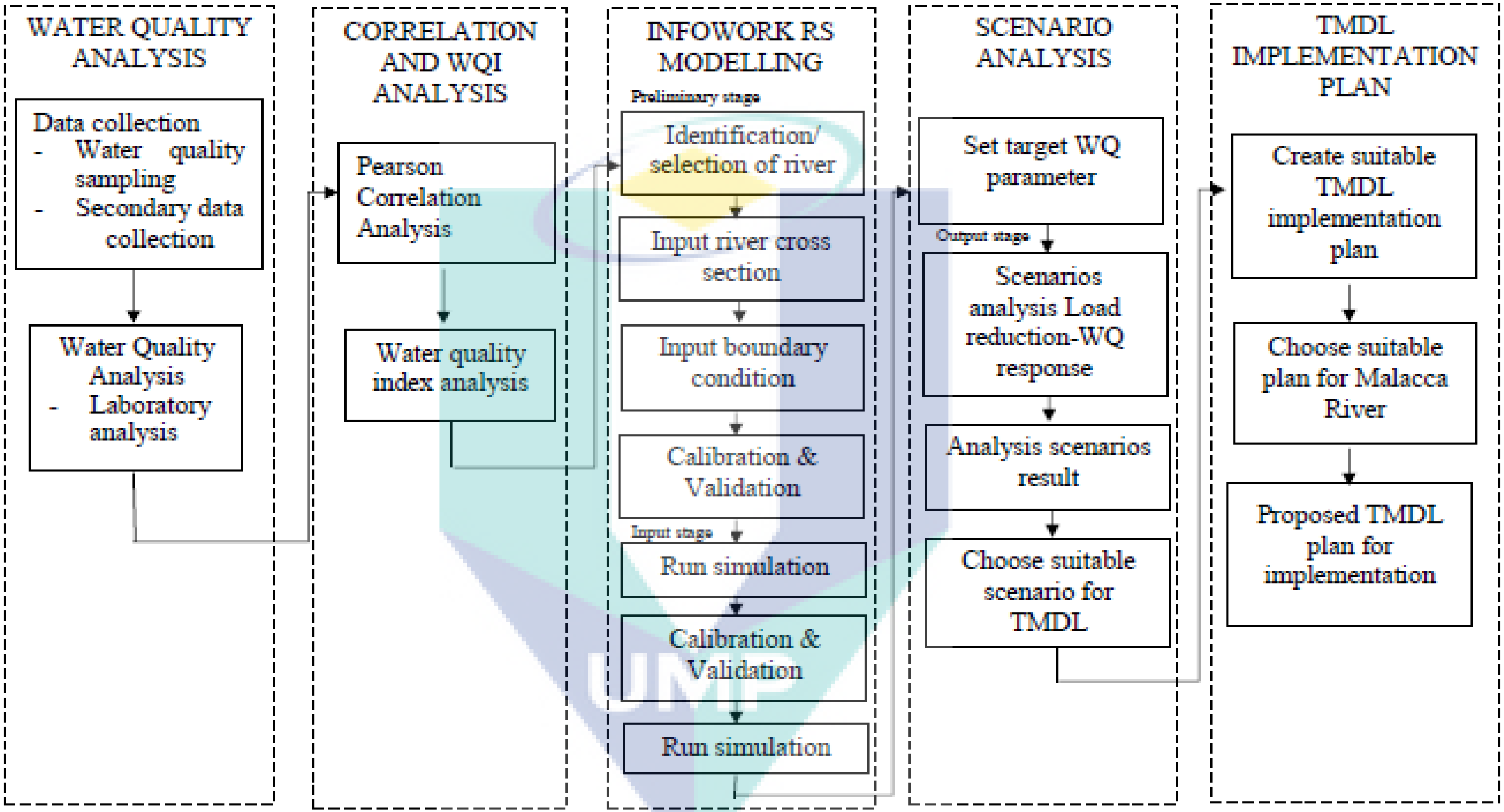


Figure 3.1 Summarization methodology framework.

There were 20 locations located at Melaka River selected for conducting water quality sampling. Besides, the tributaries data were also collected during this study (6 locations at Durian Tunggal River, 6 locations at Cheng River and 6 locations at Putat River), however, the data has not been discussed further in this study. The sampling activities were limited due to constraints of sampling procedure in terms of safety factors such as the occurrence of wild animals like crocodiles and snakes at the sampling locations. This was among the main obstacles during the sampling activities. The sampling activities were facilitated with the existence of bridges and boat services near the river. The location of sampling points along the Melaka River was discussed further in this chapter.

There was another part of the present work which includes the identification of point sources located along the Melaka River. The samples were collected during Sampling 2 (S2), Sampling 3 (S3), and Sampling 4 (S4). There were 14 sampling locations for point sources along the Melaka River The point sources location was identified along the Melaka River during the water quality sampling. The point sources location was referring to the location of specific discharge from shop lots, wastewater treatment plant and housing area. It is important to recognize the point sources location since this information was used to calculate the pollutant loading into rivers. Pollutant load of point sources was also known as a permanent source of pollution. The sampling location was selected with the recognition of point sources output that have significant contribution into the river, which assist the water quality modelling process The water quality data from the point sources were used during water quality modelling process and was discussed further in Chapter 4 (Results and Discussion).

The water quality model parts cover the process of identification of the study area, inserting the input of river cross section, input of boundaries condition, calibration and validation of the model. The model was calibrated and validated using water quality data. Once the model was calibrated and validated, the simulation was run. After the credible model has been proposed, the allowable pollutant loads calculation was carried out. The analysis was done by creating 10 scenarios of pollutant loads reduction for COD, the main water treatment parameter which has been used in this study. Based on the scenarios created, one selected scenario is taken for the development of a TMDL implementation plan. The TMDL implementation plan approach was based on the suitability of the study area and a previous study that has been done at other countries such as the United States, Korea, and China. The TMDL approach was ready to be proposed.

3.2 Location of sampling stations

The 20 locations located at the Melaka River; and all sampling plots were determined by using Global Positioning System (GPS). Besides, there was additional sampling carried out at the point sources of Melaka River, with 14 sampling stations at the main point sources of Melaka River was recognised. The collection of main point sources data was important to consider the contribution of point sources pollution into the main river during the development of water quality modelling. Figure 3.2 shows the location of sampling stations along the Melaka River. While Figure 3.3 shows the location of main point sources along the Melaka River. Besides, Table 3.1 and Table 3.2 shows the GPS location of sampling stations along the river and the description of the surrounding area.

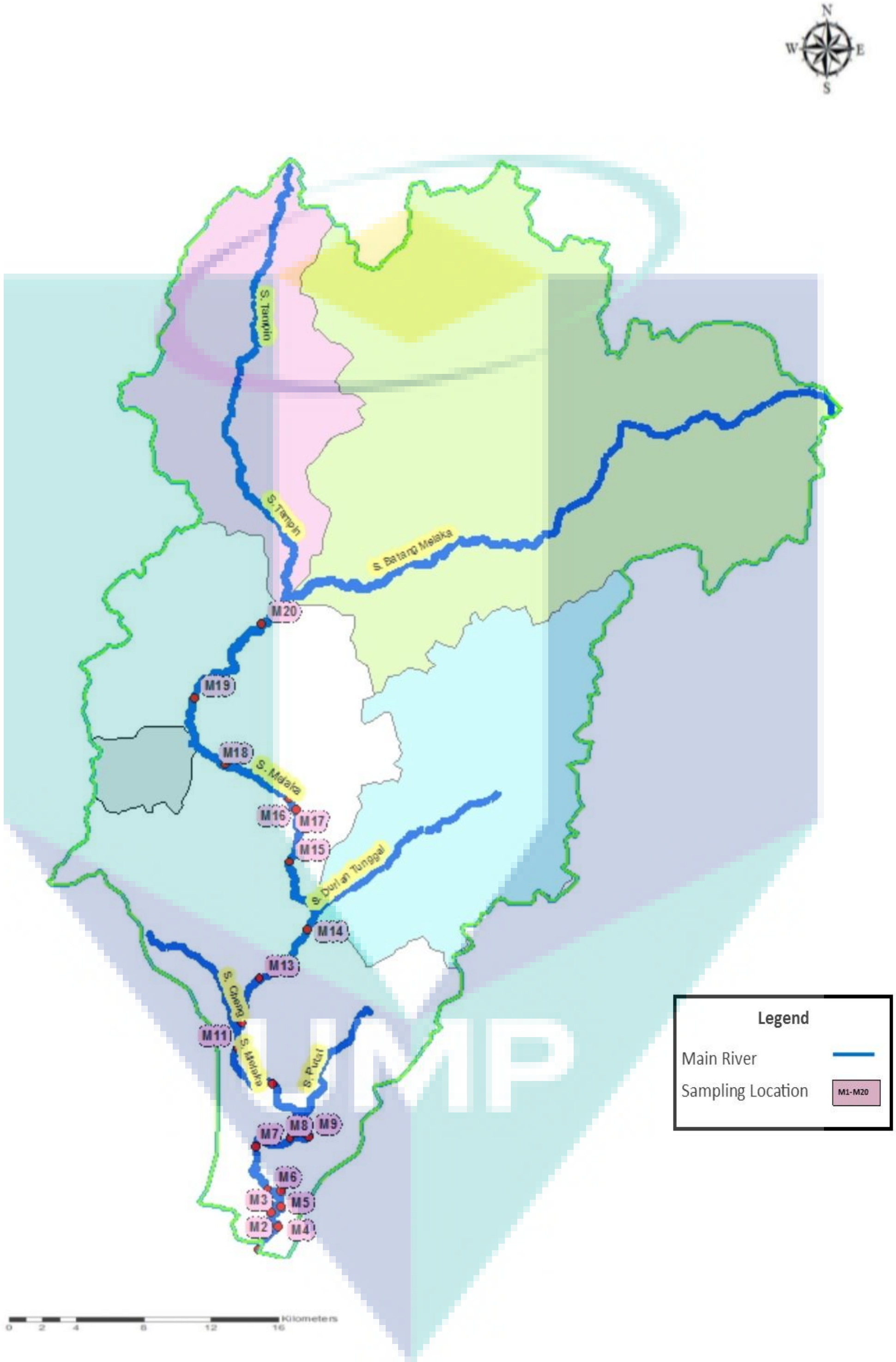


Figure 3.2 Location of sampling points along Melaka River. The map was plotted using ArcGIS version 10.2.

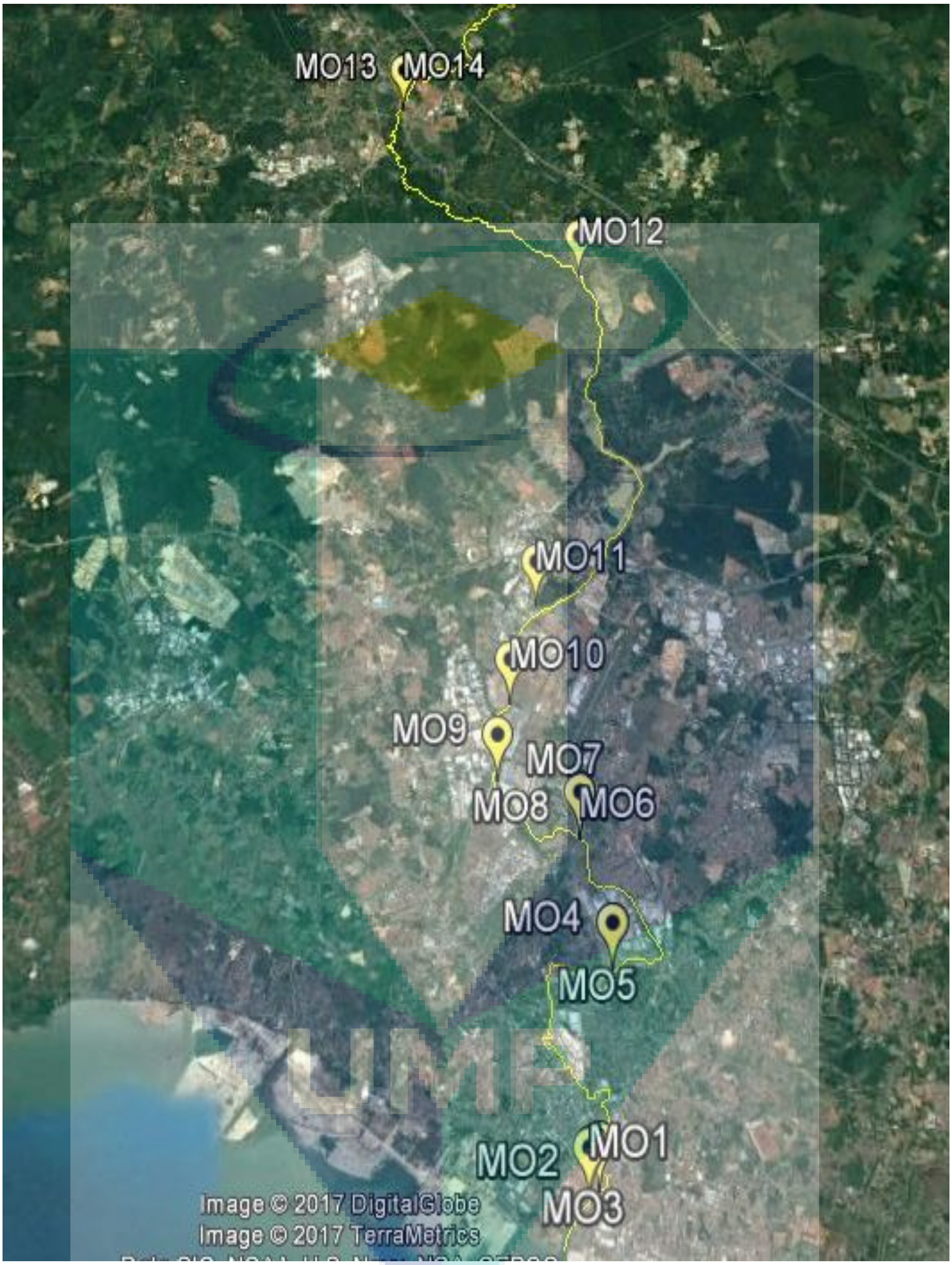


Figure 3.3 Locations of main point sources along the Melaka River. The map was plotted using Google Map.

Table 3.1 Sampling stations at Melaka River.

Location	Latitude (N)	Longitude (E)	Explanation
M1	2°11'18.48"	102°14'37.72"	Located at Melaka River mouth
M2	2°11'46.40"	102°15'01.98"	Located at Chan Koon Cheng Bridge
M3	2°12'03.30"	102°14'53.35"	Located at Hang Tuah Bridge
M4	2°12'10.71"	102°15'06.16"	Located at Morten Village Bridge
M5	2°12'29.26"	102°15'05.53"	Located at Hang Jebat Bridge
M6	2°12'32.10"	102°14'49.57"	Located at Panglima Awang Bridge
M7	2°13'22.92"	102°14'34.22"	Located at Bridge at Jalan Nangka 2, near to the windmills
M8	2°13’33.00"	102°15’16.90"	Near to the residential area at Taman Bachang Utama,
M9	2°13'35.94"	102°15'39.54"	At Jalan Dahlia 1, near to the Watergate
M10	2°14'38.84"	102°14'55.40"	Near to the Jamek Mosque, there was discharge from the outlet
M11	2°15'22.42"	102°14'11.56"	At the bridge, near to the Jalan TTC, Taman Teknologi Cheng industrial area
M12	2°15'52.00"	102°14'17.74"	At Jalan Jasa Merdeka 5, there was discharge from the outlet
M13	2°16'46.15"	102°14'38.86"	Near to the Krubong industrial area, there was discharge from the outlet
M14	2°17'45.95"	102°15'38.21"	Near to the Taman Belatuk Emas and Watergate
M15	2°19'07.40"	102°15'16.00"	At the rural area, near to the paddy field, next to the Taman Krubong Permai
M16	2°20'09.91"	102°15'23.58"	At Belimbing Dalam village
M17	2°20'23.40"	102°15'15.28"	At Beringin village
M18	2°21'04.90"	102°13'55.90"	At Palm oil estate Melaka Pindah 2
M19	2°22'24.85"	102°13'18.21"	Near to the Rumah Awan Seri Pangkalan.
M20	2°23'55.50"	102°14'41.17"	At Buloh Cina village, upstream of Melaka River

Table 3.2 Sampling stations of main point sources along Melaka River

Location	Latitude (N)	Longitude (E)	Explanation
MO1	2° 11.648'N	102° 14.857'E	Outlet discharge from shop lot
MO2	2° 11.668'N	102° 14.875'E	Outlet discharge from shop lot
MO3	2° 11.696'N	102° 14.951'E	Outlet discharge from shop lot
MO4	2° 13.478'N	102° 15.183'E	Outlet discharge from residential areas
MO5	2° 13.485'N	102° 15.189'E	Outlet discharge from residential areas
MO6	2° 14.655'N	102° 14.935'E	Outlet discharge from shop lot
MO7	2° 14.627'N	102° 14.936'E	Outlet discharge from shop lot
MO8	2° 14.626'N	102° 14.938'E	Outlet discharge from shop lot
MO9	2° 16.824'N	102° 14.606'E	Outlet discharge from residential areas
MO10	2° 17.339'N	102° 15.352'E	Outlet discharge from shop lot
MO11	2° 17.337'N	102° 15.360'E	Outlet discharge from shop lot
MO12	2° 17.394'N	102° 15.360'E	Outlet discharge from sewage treatment plant (STP)
MO13	2° 20.376'N	102° 15.244'E	Outlet discharge from residential areas
MO14	2° 22.419'N	102° 13.316'E	Outlet discharge from residential areas

3.3 Sampling procedure

The water samples were taken at each sampling locations, as well as the latitude and longitude of each station were taken using Global Positioning System (GPS), while the in-situ water quality parameters such as salinity, dissolved oxygen, pH and temperature were taken using water quality multi-parameter (EUTECH Instrument PCD650). The water depth was measured using a CMI 5-meter measuring staff, river width was measured using a measuring tape, and the river flow rate was measured using SWOFFER 300 current meter. All the apparatus and parameter are taken during the water quality sampling described in Table 3.3. There were few additional data such as previous water quality data, river cross section, and the water level was collected from DID, DOE, and JUPEM. The additional data was further discussed in subchapter 3.6 of this chapter.

Table 3.3 Parameter of water quality sampling and apparatus

Parameter	Apparatus
Latitude and longitude	Global Positioning System (GPS)
Salinity, dissolved oxygen, pH and temperature	Water quality multi-parameter (EUTECH Instrument PCD650)
Water depth	CMI 5-meter measuring staff
River width	Measuring tape
River flow rate	SWOFFER 300 current meter

3.3.1 Surface water sampling methods

The water samples were collected at a depth of 0.5 meters from the water surface. Water samples were stored in bottles, rinsed with sulphuric acid (H_2SO_4) and labelled based on the sampling location, date and time. Water samples were stored in the ice box at 4 °C. The samples were stored in the dark and cold, to prevent loss of nutrients due to biological activity. Moreover, additional information related to the sampling locations such as weather and environmental activities is recorded to facilitate the research.

3.3.2 Chemical parameter analysis

There were seven parameters tested in the laboratory, which is biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), phosphate (PO_4^{3-}), total nitrogen (TN), Ammoniacal nitrogen (NH_3-N), and total suspended solids (TSS). The BOD (BOD_5) analysis was done with the initial DO analysis were taken as soon as reach to the laboratory and the water samples were kept in an incubator for 5 days. Phosphate analysis was done within 48 hours of samples collected to avoid interference of another parameter. All laboratory analysis was done within 7 days of samples collection. The laboratory analysis of ex-situ parameter was conducted in accordance with the standard method (American Public Health Association, [APHA], 2005). The list of chemical parameters and methods adopted for analysis are shown in Table 3.4.

Table 3.4 Methods used for chemical parameters analysis.

Parameters	Methods
BOD	BOD_5 (APHA-5210-B)
COD	Open Reflux Method (APHA-5220-B)
NH_3-N	Phenate Method (APHA- 4500 NH_3-F)
PO_4^3	Ascorbic Acid Method (APHA-4500 P-E)
TN	Titration Method (APHA-4500 NH_3-C)
TP	Vanadomolybdophosphoric Acid Colorimetric Method (APHA-4500 P-C)
TSS	Total Suspended Solid Dried 103°-105° (APHA 2540 D)

For the total suspended solids (TSS) analysis, the water samples were filtered using 0.45µm of mesh pore size of filter paper upon arrival at the laboratory. The filter papers used were weighed before and after used and then dried in an oven. The dried filter paper samples were used as samples for total suspended solids of surface water. The water samples were stored in the refrigerator until analysis was performed.

3.3.3 The physical parameter of the river

A physical parameter such as flow rate and river cross-section were measured during the sampling. The water flow rate was obtained by measuring the velocity at a certain point in the situation of vertical air flow meter by using H.P. reference No 15 (DID, 1995). Velocity distribution between surface water and river bed approaches parabolic shape, approaching zero velocity at the base and maximum velocity at about 1/3 below the water surface. The water flow rate obtained through observation of the velocity at some selected points are as follow:

a. Method one point located 0.6 of the depth of the surface (0.6d)

b. Method two points, a point located at 0.2 and 0.8 of the depth of the surface (0.2d, 0.8d)

c. Method three points, a point located at 0.2, 0.6, and 0.8 of the depth of the surface (0.2d, 0.6d, 0.8d)

Measurement of the area of river cross-section was carried out by measuring the width and depth of the river. The number and vertical distance depend on the cross-sectional shape, and the distribution of horizontal velocity, usually non-uniform cross section has a non-uniform velocity distribution. A measuring tape was used to measure the width of the river while for depth of river must be recorded on each upright vertical distance from the surface of the water right up to the river bottom as shown in Figure 3.4.

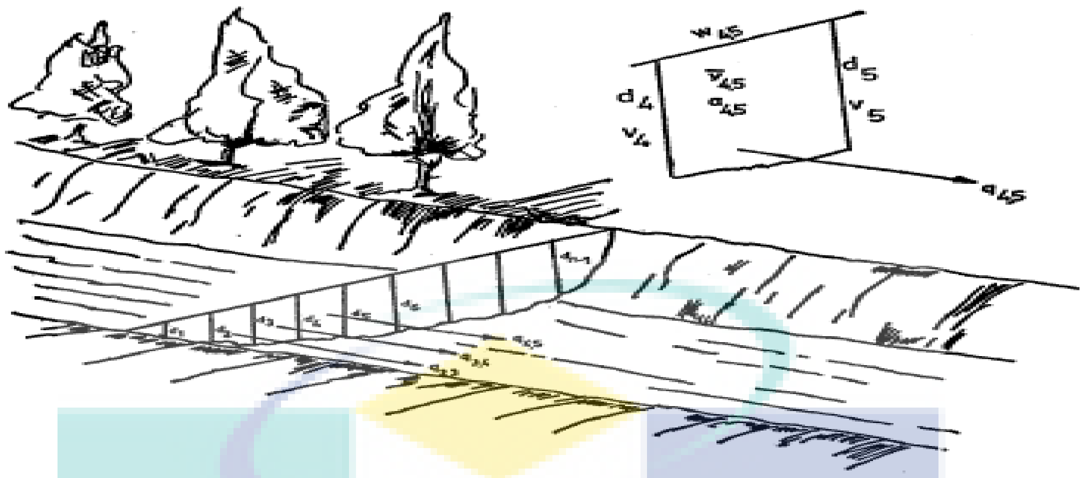


Figure 3.4 Measurement of depth, width and flow rate of the river.
Source: DID, 1995.

The velocity of the river was obtained by using the current meter. This information was used to calculate the river discharge. River discharge (Q) was calculated by using equation 3.1, which a mean velocity of flow and cross-sectional wetted area as shown below (Kim et al., 2019).

$$\text{River discharge (Q)} = \text{Area } (m^2) \times \text{Velocity (m/sec)} \qquad 3.1$$

3.4 Pearson Correlation Coefficient Analysis

The water quality data were analysed based on statistical analysis method using SPSS version 20.0. SPSS is a Statistical package for the social science which a program for manipulating, analysing, and presenting data (Sebjan & Tominc, 2015). Statistical tests were conducted to support and strengthen the data analysis. The Pearson Correlation Coefficient (r-value) analysis was one of simple correlation analysis can be done by using SPSS to study the significant correlation between the water quality parameter. The r value was constrained with $-1 \leq r \leq 1$, where (1) Positive r values shows positive linear correlation; (2) Negative r values shows negative linear correlation; (3) A r-value of 0 shows no linear correlation; and (4) The closer r value to 1 or –1, the stronger the linear correlation (Mustapha et al., 2013). The significant level (p-value) used in this study were 0.01 % and 0.05 %. The significant level was interpreted as below:

i. P value > 0.05 %: insignificant correlation

ii. P value < 0.05 %: Correlation is significant at the 0.05 level (*)

iii. P value < 0.01 %: Correlation is significant at the 0.01 level (**)

3.5 Water quality index and water classification

Water Quality Index (WQI) was basically used to measure the water quality level that categorized into five classes which is Class I, Class II, Class III, Class IV and Class V. The classification of the classes as shown in the appendix. The calculation of WQI was done for Melaka River to study the classes of water quality and level of river health, were based on DOE-WQI (Juahir et al., 2011). Besides, WQI was used to make a comparison of the water quality between different sampling points of a river or between different watersheds. WQI calculated is between 0 until 100. WQI can be calculated by using the formula as shown in equation 3.2 (WEPA, 2006; Othman et al., 2012; Ismail et al., 2016):

$$WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SISS) + (0.12 * SIpH) \quad 3.2$$

Where;

SIDO =Sublndex DO (% saturation)

SIBOD = Sublndex BOD

SICOD = Sublndex COD

SIAN = Sublndex NH_3-N

SISS = Sublndex SS

SipH = Sublndex Ph

3.6 InfoWorks RS Modelling

The water quality modelling was performed by using InfoWorks RS version 10.5. The methodology for water quality model development was referred based on River Hydrodynamic Modelling - The Practical Approach manual (Hassan, 2005) and Water Quality Modelling in InfoWorks Integrated Catchment Modeling (ICM) (Innovyyze, 2012). InfoWorks Water Quality was a computer program used to model water quality in open channels. The quality simulation engine was separated from the hydraulic engine (which provides the hydrodynamics), and therefore water quality simulations required two separate simulations. The first part was the hydraulic model and the second part was one or more water quality simulations for the hydrodynamic data. The water quality modelling using InfoWorks RS version 10.5 was summarized in Figure 3.5.

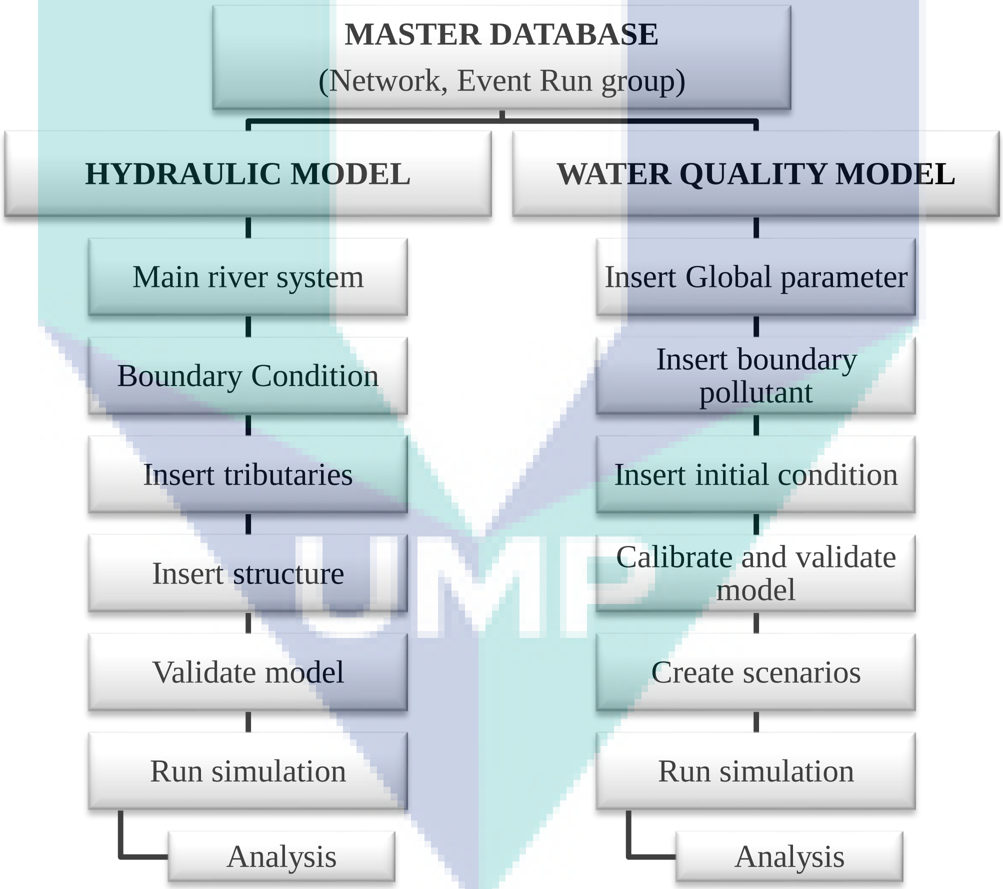


Figure 3.5 Water quality model analysis using InfoWorks RS version 10.5.

In this model, a master database was created. The master database was important for storing all the information and data regarding the model. Once the master database was created, it was necessary to create a model group. It can contain one or more model group. The master database contained the network model, event model, water quality model, and run group model. By having a master database, all the model data and result were easily managed and stored.

3.6.1 Hydraulic Model

The hydraulic model was created for the network, event and logical control. The network represents the main river system. Figure 3.6 shows the main river system of the Melaka River. The network was displayed in the GeoPlan view. The channel and structure parameters were defined in the network which does not change over the time covered by the simulation.

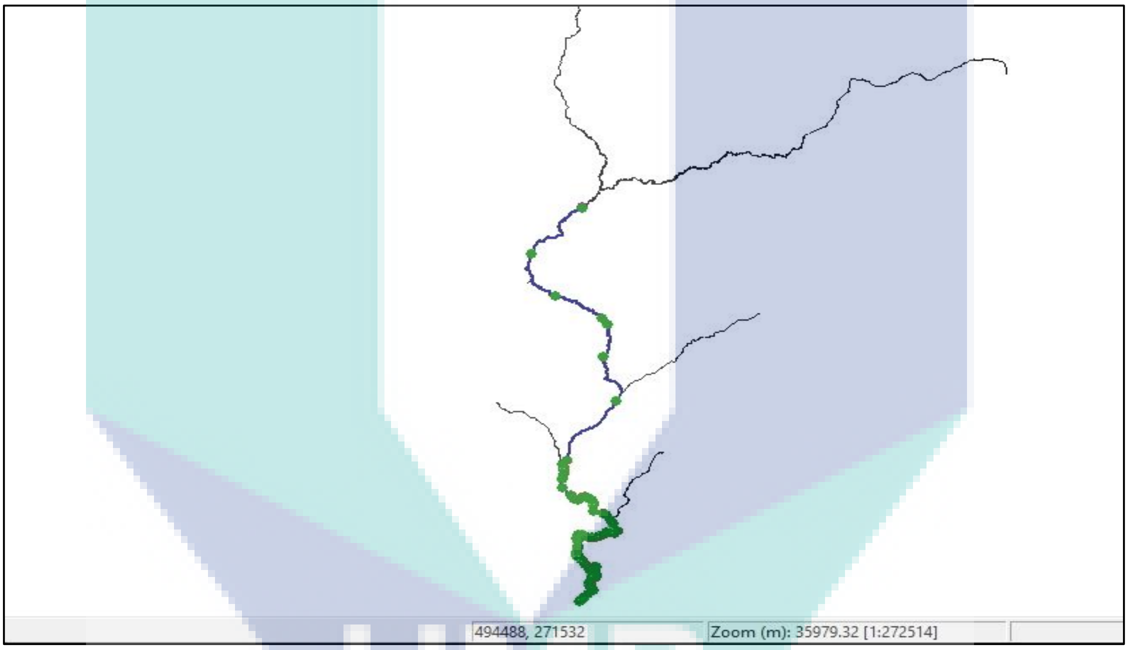
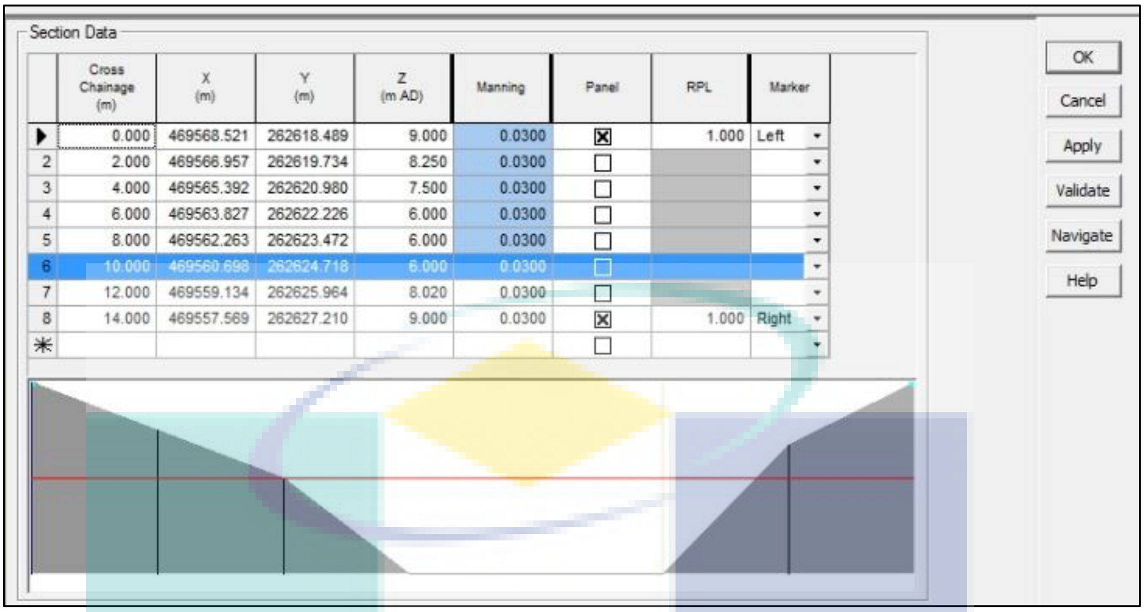


Figure 3.6 Main river system of Melaka River displayed in Geo Plan

Time-varying parameters and initial conditions were stored in a separate Event Data Set. The networks were created from imported external source, the data of Geographic Information System (GIS) from the DID. The cross section for each channel in the main river system was inserted manually based on data provided. Figure 3.7 shows the cross section of channels at the Melaka River.



	Cross Chainage (m)	X (m)	Y (m)	Z (m AD)	Manning	Panel	RPL	Marker
1	0.000	469568.521	262618.489	9.000	0.0300	☒	1.000	Left
2	2.000	469566.957	262619.734	8.250	0.0300	☐		
3	4.000	469565.392	262620.980	7.500	0.0300	☐		
4	6.000	469563.827	262622.226	6.000	0.0300	☐		
5	8.000	469562.263	262623.472	6.000	0.0300	☐		
6	10.000	469560.698	262624.718	6.000	0.0300	☐		
7	12.000	469559.134	262625.964	8.020	0.0300	☐		
8	14.000	469557.569	262627.210	9.000	0.0300	☒	1.000	Right

Figure 3.7 Cross Section of channels inserted in the main river system.

The network was validated to use in a simulation and the output window from the validation process can be viewed. The output window was displayed the error occurs in the model. The error was modified before the simulation was run. To edit the network, the network must check out. The long section of the Melaka River was shown in Figure 3.8, where the view of the river was from upstream to the downstream.

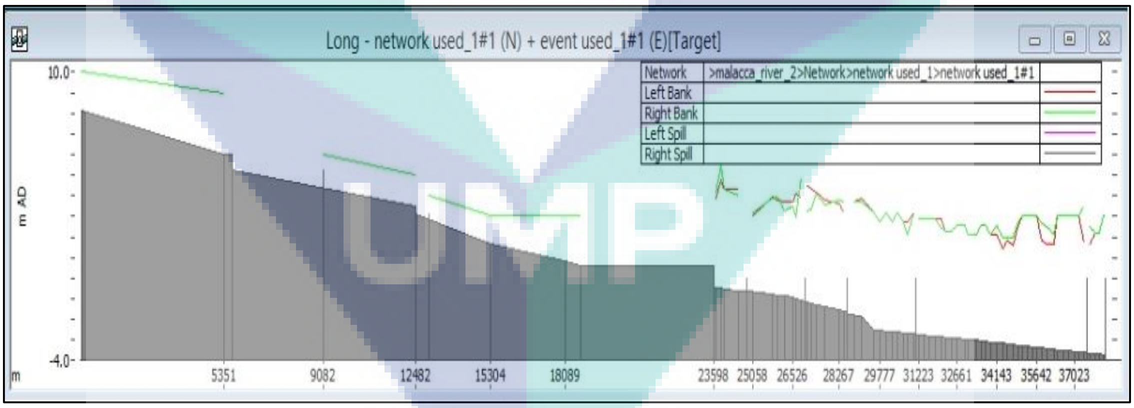


Figure 3.8 Long section of main river system for Melaka River.

The event data were inserted after completed inserting the network data. The event data explain the network of the river that varies with time during the simulation and clarify the information about the initial state of the network at the beginning of the simulation. This process includes inserting the data of inflow and outflow boundary conditions, the initial conditions for all the nodes and links in the network, and the control data for some structures in the network. The upstream boundary node was using the flow-time event data types, while the downstream boundary node was using the stage-time data types. Time-varying data was kept separated from the fixed network data to simplify the modelling process. The multiple event data sets can be used in a run to create a set of simulations.

After finished inserted the event data, the model was required to validated once again. The validation process ensures the model was able to run the simulation. When carrying out simulations, the most important component of the InfoWorks master database was the Run Group. The Run Group contains one or more Runs. Each run group can contain one or more simulations. The model was run for the steady simulation to create the initial condition for unsteady simulation. The initial condition that created during the steady state, to make sure every nodes and link within the network have the initial condition before the simulation were run. Steady state also known as convergence criteria of parameter listed in the network.

After the simulation is done, the result was analysed based on purpose and interest. The progress of simulation can be reviewed in one of three ways. The simplest progress of simulation was the Log Report. Log Report contained the output from the simulation engine, any warnings or other important information generated at each time step during the model run. The simulation was replayed with the output displayed on either the GeoPlan View, Long Section view, or results versions of the Grid Views. The GeoPlan provides powerful tools for graphically displaying the changing state of the network over the period of the simulation. Figure 3.9 shows the long section view of simulation analysis for the Melaka River.

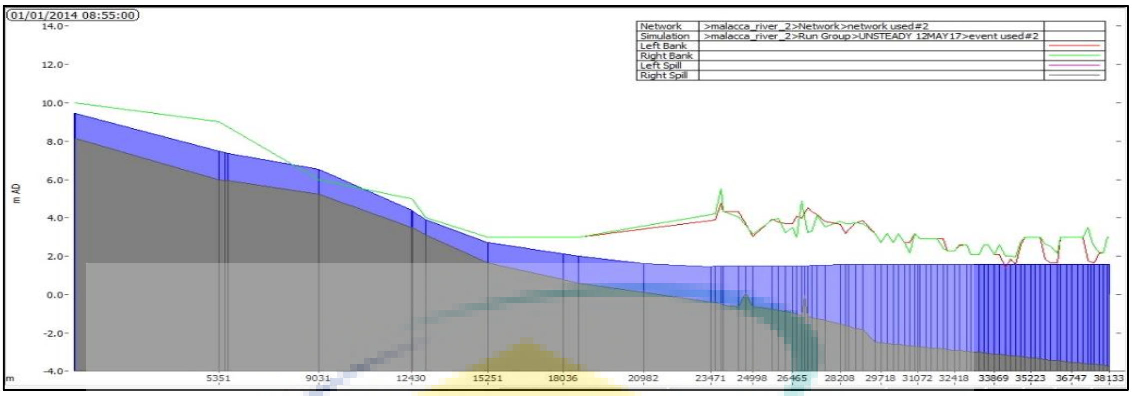


Figure 3.9 Long section view of simulation analysis for Melaka River.

3.6.2 Water quality model

The InfoWorks Water Quality module was used for modelling water quality in open channel systems such as rivers and estuaries. The transport of pollutants was modelled by a finite difference approximation to the one-dimensional advection-diffusion equation (Gaskell & Lau, 1988). Model boundaries were represented as concentration-time or concentration-flow relationships (Innovyyze, 2012). Pollutants can also be introduced at, or removed from, any point in the model. InfoWorks simulation can model a range of water quality variables and processes simultaneously. These include:

i. Conservative pollutants

ii. Decaying pollutants

iii. Coliforms

iv. Salt

v. Water temperature

vi. Sediment

vii. DO, BOD/COD

viii. Water/Sediment oxygen interactions

ix. pH

In the present work, a few parameters data were required to run the water quality model such as DO, BOD, COD, pH, and temperature. InfoWork RS for Water Quality was written in a modular fashion, therefore not all the processes or parameters were required to be analysed at once. However, some of variable and process need to interact in the river environment, therefore it is impossible to run some modules without including the other features. Figure 3.10 shows the dependency of different modules to another module, for examples if the pH modules were required to run, the temperature and DO module need to be run as well. Whereas, the conservative pollutant, decaying pollutant and salt module was an independent module.

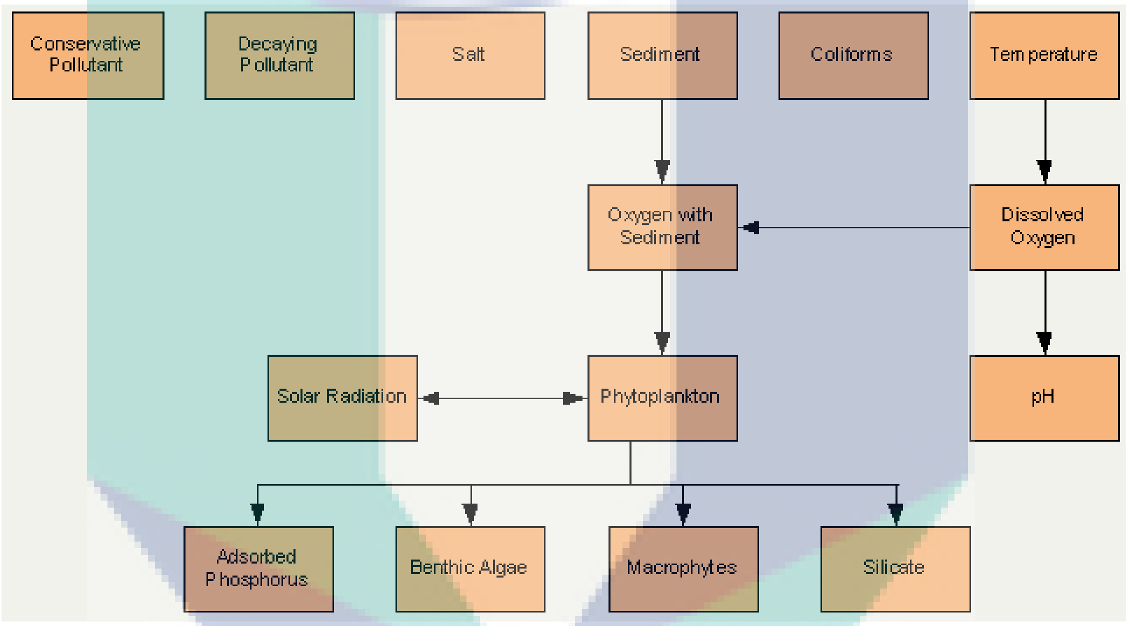


Figure 3.10 Dependency on water quality module based on process and variables.

The water quality model was run after the hydraulic run was done. The hydraulic analysis was important to provide flow data for the water quality run. However, to ensure the hydraulic analysis can be used for water quality run, the 'Write Water Quality File' option was ticked during the hydraulic run. The water quality model was required to insert the global parameter properties. This option was important to select which water quality processes are modelled. The related model was selected for water quality analysis in Melaka River. The model was chosen based on the available data at Melaka River. The limited data available usually minimised the opportunity to run the favourable model.

Each inflow boundary must have a boundary node within the water quality object. The water quality boundary name does not have to be the same as the name of the network node to which it was assigned. The boundary conditions were set as concentrations of the dissolved or suspended variable, except in the case of DO where it can be elected to specify the percentage saturation, instead of the concentration. The concentration can be allowed to vary with time or with the discharge of pollutant loads.

The boundary Pollutant profiles were entered as Flow-Time or Flow-Concentration pairs. The water quality model for the Melaka River was used Flow-Concentration condition for each water quality parameter. The initial condition for the Melaka River model was created and validated before running the simulation. The simulation was run using the water quality observation dataset.

The results from the analysis were used to calibrate the model by using Excel software. The modification of the model was made to fits the requirement based on the calibration analysis. Based on the calibration result, the scenario of pollutant loads reduction for water quality analysis was created. The simulation was run based on the scenario created. The result from the simulation was exported into a CSV file and was analysed using Excel.

Based on the chosen scenario analysis, the TMDL implementation plan was developed. The best condition was chosen for the proposed implementation plan to reduce the pollutants loading.

3.7 Total Maximum Daily Load (TMDL) Implementation Plan Approach

The TMDL implementation plan approach for the Melaka River was accountable for the maximum amount of a COD pollutant that can receive by the river, while it still achieved Class IIB water quality standards, therefore the allocation of the loads was done for the point sources (WLA) and nonpoint sources (LA) of pollution.

On the other hands, the TMDL for Melaka River also consider the seasonal variations in water quality, which included the margin of safety (MOS) for uncertainty in predicting how much pollutant reductions will be resulted in meeting water quality standards. The MOS of TMDL for Melaka River was express in explicitly by using the conventional method, which MOS at 10% (Patil & Deng, 2011). EPA guidance also suggested the 10 % of MOS from the load allocation were reserving explicitly (Freedman et al., 2008). The TMDL can be simplified based on equation 3.3 below (Fakhraei et al., 2017):

$$TMDL = \sum WLA + \sum LA + MOS \quad 3.3$$

The pollution sources in the TMDL were characterized as either point sources that receive a waste load allocation (WLA) such as sewage treatment plant, industrial facility or stormwater, or nonpoint sources that receive a load allocation (LA) or from natural background such as farm runoff and atmospheric mercury (Wu & Chen, 2013). MOS can be described as the margin of safety, can be determined in implicitly or explicitly, where the implicitly used conventional model assumptions, while explicitly takes a portion of total TMDL as MOS using the remainder for allocations (Camacho et al., 2018).

There were a lot of methods used to develop TMDL in a watershed, ranging from the simplest, by using mass balance equations and load duration curves, right up to a wide range of difficulty levels of the model, which is water quality model (Hernandez et al., 2008; Gaddis et al., 2010). In this study, the water quality model was chosen as the planning tools for TMDL approach at Melaka River, based on the changes of physical, chemical, and biological characteristics of water bodies, as defined by a mathematical equation to predict the pollutant loading in the river (Song & Kim, 2009). Water quality model establishes a cause-effect relationship between the load reduction and the water quality responses, in order to support water quality management decision making (Wang et al., 2013).

The whole process of TMDL implementation plan approach for the Melaka River was shown in Figure 3.11. The TMDL implementation plan for the Melaka River was proposed based on the violation of water quality at the river. The watershed characterization was the process of gathering and collection of river data. All the data were important to determine the water quality status of the river and gained a basic understanding of the water body. The data was collected using several methods as follow:

i. Water quality sampling (August 2014- October 2014)

The data collected such as water quality data, river cross section, river flow rate, water depth, observation of activities along the Melaka River.

ii. DOE (2003- 2013)

The water quality data from DOE water quality station available at the Melaka River from 2003-2013.

iii. DID (2003-2013)

The water quality data from DID water quality station available at the Melaka River, cross-section data, water level, and streamflow from 2003-2013.

iv. JUPEM (2013)

The water level data from the tide prediction table at Tanjung Keling, Melaka was the nearest tidal station in Melaka for the year of 2013.

Based on the data collected, the river was characterized, and the impairment of the water body was recognized. Analysis of all the available relevant data was performed within the scope of this study. The analysis includes evaluation of spatial and temporal analyses of a few water quality parameters and presented in Chapter 4. In this study, the Malaysia water quality standards based on WQI was initially referred. Depends on the target water quality standards need to achieve at Melaka River, the TMDL approach to improve the water quality impairment occurs in the watersheds. The water quality parameter was easily identifiable and quantifiable. Therefore, one single water quality parameter was used for reference. From the water quality analysis of data collected, the Melaka River was classified in Class III. Therefore, the target water quality standard desired to be achieved at Melaka River was sets up based on the activities along the river, which is Class IIB. The selected target parameter for TMDL implementation plan approach is COD. The COD was chosen according to the violation of this parameter along the Melaka River. Even though only one parameter was taking care during the TMDL, the other parameters will be significantly reduced according to the previous study.

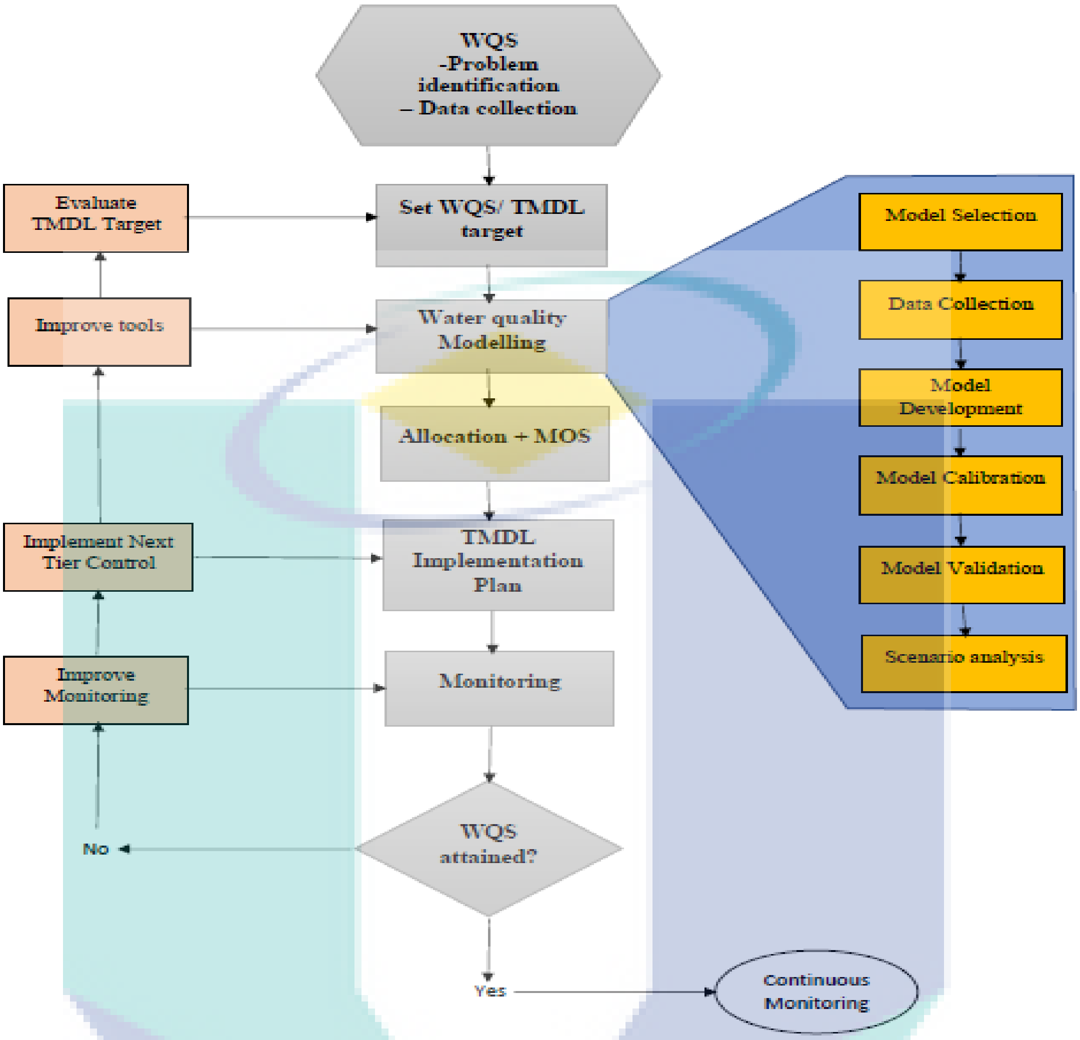


Figure 3.11 Formulation of TMDL implementation plan approach at the Melaka River

Source: Chapra (2003); Freedman et al. (2004); Zhang et al. (2015).

The suitable water quality model was selected, which is InfoWork RS version 10.5, as the planning tools in TMDL program, for determining the quantitative relationship between pollutant sources and water quality target (DePinto et al., 2004) and the process was discussed in subchapter 3.5. From the water quality modelling, the scenario analysis was created and analyse. The 10 scenarios were analysed through the Melaka River, to find the suitable condition would be highly effective at achieving the target water-quality standard compliance throughout the watershed and TMDL target can be achieved (Love & Whitney 2008). Results of scenarios from the model simulation were analysed and only one suitable scenario was chosen for TMDL implementation plan approach. Based on the selected scenario from the model, the allocation of WLA, LA and MOS were determined. To achieve the allocation of WLA, LA and MOS, the suitable

TMDL implementation plan was initiated. The pollutant load for the loading capacity was calculated in equation 3.4 as below. The TMDL was carried out based on suitability of the Melaka River to control the point sources and nonpoint sources pollution.

$$\text{Loading } \left(\frac{\text{kg}}{\text{d}}\right) = \text{Flow rate } \left(\frac{\text{m}^3}{\text{d}}\right) \text{ x Average COD concentration } \left(\frac{\text{mg}}{\text{L}}\right) \qquad 3.4$$

Furthermore, this study also proposed the monitoring program after the implementation of TMDL. The monitoring program was proposed according to the available sources and data, to reduce the cost of water quality monitoring. On the other hands, the TMDL implementation plan also provides the timeline of the program to be the monitor. Since Malaysia never have experience in implementing TMDL, the potential agency to monitor the program was also suggested. From the monitoring program, the achievable of desired water quality standard can be determined. If the water quality standard was not attained, all the process needs to review and improved. Whereas, if the water quality standard was attained, the monitoring program would continue to ensure the water quality of the river will be enhanced.

Based on the guide on TMDLs from US Environmental Protection Agency (EPA), it emphasizes the importance of the stakeholders' engagement and the public participation in developing TMDL at all phases or processes. The common processes of developing TMDLs involved stakeholder engagement and public participation. In this study, a survey was done to determine the level of understanding and acceptance of the stakeholders on the TMDL program. The stakeholders involved in this survey was staff from DOE, DID, National Hydraulic Research Institute of Malaysia (NAHRIM), Perbadanan Pembangunan Sungai dan Pantai Melaka (PPSPM), Indah Water Konsortium (IWK), Badan Kawal Selia Air (BKSA), Department of Town and Country Planning (PLANMalaysia), and Malaysia Public Works Department (JKR). In addition, the challenges for the TMDL approach in Malaysia also has been discussed in Chapter 4.

3.8 Summary

This chapter was important to give the overall of the methodology used in this study. The water quality analysis was done by collecting the data from the water quality sampling and secondary data from the DOE, DID and JUPEM. The data from the water quality sampling was analyse by doing the laboratory analysis. From the laboratory data, the correlation analysis by using Pearson Correlation Coefficient was done the shows the correlation occurs between the target parameter of TMDL, which is COD and other parameters. The correlation analysis was important to show of the improvement of COD during the TMDL approach can significantly improve the other parameters that correlated with it. The WQI analysis was done to determine the water quality status of Melaka River, then the target water quality standard of TMDL for Melaka River can be set up. The methodology for water quality modelling by using Infowork RS version 10.5, was discussed in this chapter, to show how the model was developed. The picture of the TMDL implementation plan approach was discussed further in this chapter. This chapter provide significant information needed at every stage of the methodology used in this study that assist during the TMDL development for Melaka River.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the finding of this study was discussed briefly, including water quality assessment results, water quality model results and the TMDL approach. The TMDL implementation plan was created to address COD impairment in the Melaka River. The main goal of TMDL was to quantify the pollutant loads reduction needs to meet the Malaysia water quality standard for COD. Recently, Melaka River was often associated with environmental pollution problems resulting in outstanding issues such as the death of the fish. Rapid development and the increase in population, without the presence of a specific monitoring system and strategies for the preservation of the river has led to the adverse effect in water quality. Based on the water quality monitoring data conducted by the DOE from the years 2011 to 2017, the water quality status of the Melaka River was in Class III, particularly near to the downstream of Melaka City. This has encouraged the government to take efforts to restore water quality in the Melaka River. To restore the river water quality, this present work was carried out to identify the major contributors of the pollution to the river and come out with the strategy to reduce the sources of pollutants effect.

This chapter captured the overall picture of the water quality status of the Melaka River and the contribution of COD into the impairment of river pollution. The result of the physicochemical parameters was analysed in spatial and temporal variation. The results were also analysed by using statistical analysis which is Pearson Correlation analysis to determine the sources of water pollution. The water quality index (WQI) of Melaka River were also determined in this chapter, according to the sampling 1 to sampling 4 (S1-S4). The average values of WQI indicate the river water quality status of the Melaka River. The water quality analysis was important in this study to provide significant information for the TMDL implementation plan.

Based on the water quality analysis, the water quality model framework was built using InfoWorks River Simulation (RS) version 10.5 for the Melaka River. The Melaka River was located within the Melaka watershed which consisted of five main tributaries; (1) Batang Melaka River, (2) Tampin River, (3) Durian Tunggal River, (4) Cheng River, and (5) Putat River. The pollution from tributaries was the main contributor to the development of a water quality model, where each source from the tributaries was contributed to the pollution levels prevailing in the Melaka River. In this study, the model was calibrated using the available data which has been discussed briefly in this chapter. According to the water quality assessment, correlation analysis and WQI analysis, COD was chosen as the TMDL target parameter to be reduced. There were 10 scenarios for COD loads analysis been created and analysed in order to ensure the improvement of water quality can be achieved. From the 10 scenarios created, only one suitable scenario for COD loads was chosen for TMDL implementation. Based on analysis derived from water quality model, the implementation strategies of TMDL was proposed.

TMDL implementation plan approach was a critical part of this study. As mentioned in the previous chapter, TMDL can be described as the maximum amount of total pollution loading can enter the water bodies while still maintaining the water quality of the river within the acceptable level (Ormsbee et al., 2004). TMDL has been well establishing in the United States (US) (Keller & Cavallaro, 2008; Mirchi & Watkins, 2012), and a few Asia countries such as South Korea (Poo et al., 2007; Lee et al., 2013; Kim et at., 2016), and Taiwan (Hsieh & Yang, 2006). However, in Malaysia, the TMDL approach has been started to be studied as the first proposed TMDL approach has been suggested in the 11th Malaysia Plan (Rahman, 2015). The study focusing on the TMDL should be carried out immediately since it was a very good method in monitoring the river water quality. In this chapter also, the monitoring plan for implementation strategy and the challenges for the TMDL approach in Malaysia has been discussed.

4.2 Water quality standard and target parameter

TMDL implementation plan was created according to the water quality target need to achieve for each pollutant concern in the study area. The numeric numbers of water quality standard were used as the TMDL target. In Malaysia, based on DOE specification, to achieved Class II of river water quality, the value of COD must below than 25 mg/L. Table 4.1, describes the criteria of target water quality of TMDL. The Class IIA water quality target was suitable for water supply with conventional treatment and fishery activities for sensitive aquatic species. While for Class IIB can be used for recreational activities with body contact. Melaka River needs to achieve Class IIB, especially at the downstream area because there are a lot of recreational activities occurs and tourist attraction in that area. The overall goal of the TMDL implementation plan for Melaka River was to achieve Class IIB water quality standard.

Table 4.1 Water quality standard and classes for the COD parameter.

Parameter	Class	Value	Uses
Chemical Oxygen Demand (COD)	Class IIA	≤ 25 mg/L	Suitable for water supply with the conventional treatment. Suitable for the fishery activities for sensitive aquatic species.
	Class IIB		Recreational use body contact.

4.2.1 COD trend analysis

The COD parameter was analysed by using the trend analysis of time series based on the available water quality data. This analysis determines the COD concentrations changed over time or vary seasonally and provide the potential sources of COD pollutant. Based on data provided from DID and DOE, there were two water quality monitoring stations located at Melaka River, which are 1M12 (DOE station) and 2322614 (DID station). The 1M12 located at downstream, while 2322614 located at upstream of Melaka River. The trend of COD concentration was analysed from 2003 until 2013 according to the data provided by DOE and DID as shown in Figure 4.1 and Figure 4.2, respectively. The COD trend analysis shows a distinct level at the downstream and upstream station. The downstream station (1M12) found higher COD concentration compared to the upstream station (2322614). This trend proved that there was a higher contribution of pollution sources at the downstream of the Melaka River, which significantly affected the river water quality. Rosli et al. (2015), found the downstream of Melaka River was classified as Class III, due to high population density and rapid development activities. According to a study by Hua (2015), the various sources of contribution from the industrial waste excretion waste at Melaka River has caused the water in the river to become black colour, smelly and contaminated. Both stations show the decreasing trend of COD concentration change over time, but the concentration of COD still higher than Class IIB according to NWQS. It is important to overcome this problem before it gets worse. Therefore, this study has chosen COD as a target parameter for TMDL approaches.

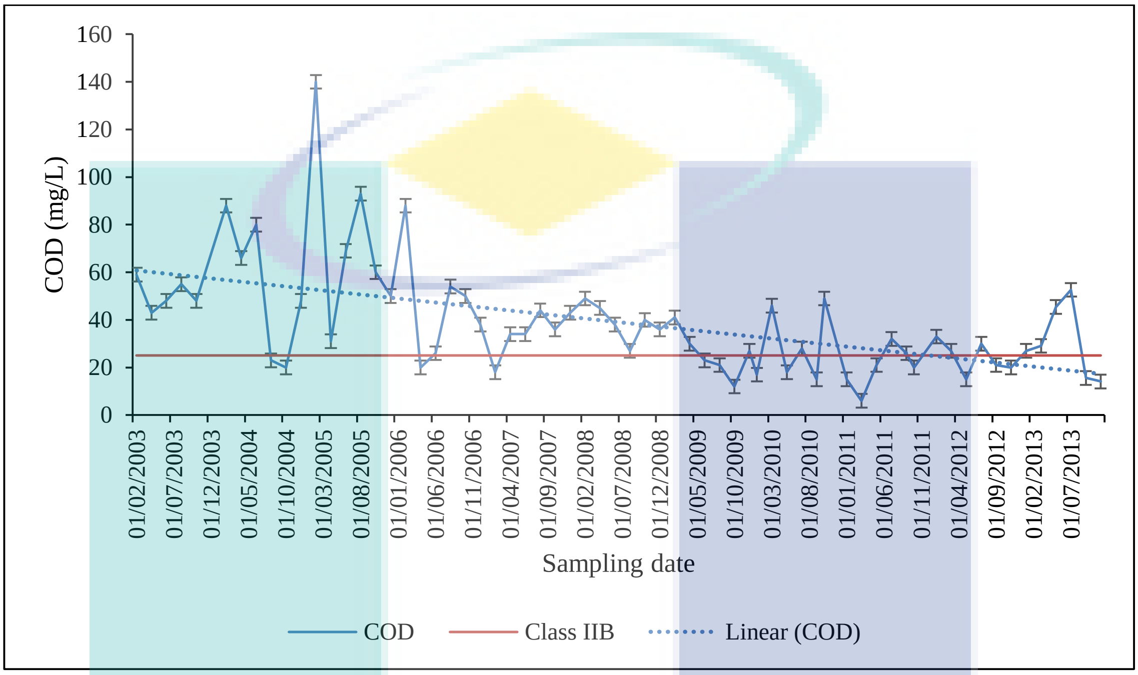


Figure 4.1 Trend of COD at DOE water quality station (1M12) from 2003-2013

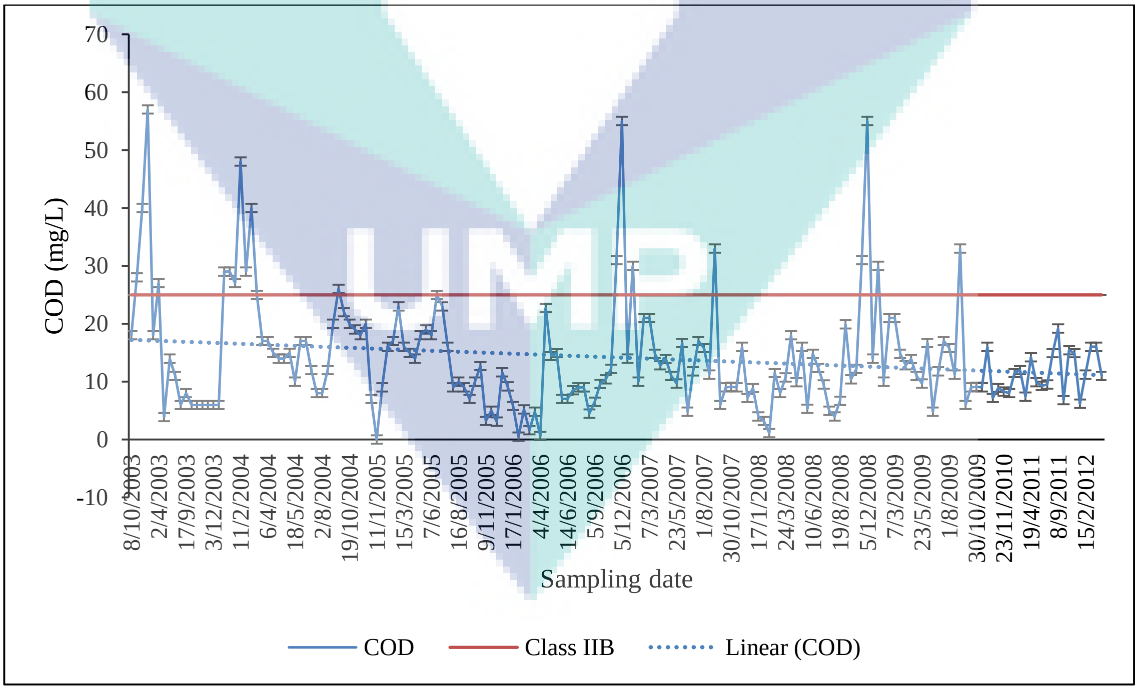


Figure 4.2 Trend of COD at DID water quality station (2322614) from 2003-2013.

Besides, the COD concentration during the four times sampling (S1-S4) analysis was done from August 2014 until October 2014, to study the water quality of Melaka River. Based on sampling, the COD concentration was analysed, in Figure 4.3 shows the spatial variation of COD concentration along the Melaka River, indicate the range from 10.16 mg/L at M14 to 365.54 mg/L. Higher concentration of COD was recorded at downstream of Melaka River (M1), which shows the intrusion of anthropogenic sources into the water bodies. A study by Hossain et al. (2014), found the values of COD relatively higher at the downstream of the river due to the dense of industrial activities, which supported the finding of higher COD values at the downstream of the Melaka River.

A study was done by Mohamed et al. (2015) at the Klang River recorded a higher value of COD (387 mg/L) due to the sampling location located at urban areas that exposed to the many point sources pollution. This situation also occurs at the M1 sampling location that experienced many activities along the site. Besides, the higher value of COD (329 mg/L) also has happened at Terengganu River which the location was polluted with anthropogenic sources such as domestic waste and industrial waste (Ibrahim et al., 2014) The downstream area of Melaka River was found as the highly polluted area from the previous study (Rothenberger et al., 2014) with many residential and commercial activities occur there (Hua & Ping, 2016). The range of COD value was widely separate between the sampling locations. The value of COD at five sampling locations shows the value is less than 25.00 mg/L, at M9 (22.30 mg/L), M11 (24.34 mg/L), M14 (10.16 mg/L), M17 (12.10 mg/L), and M20 (15.28 mg/L).

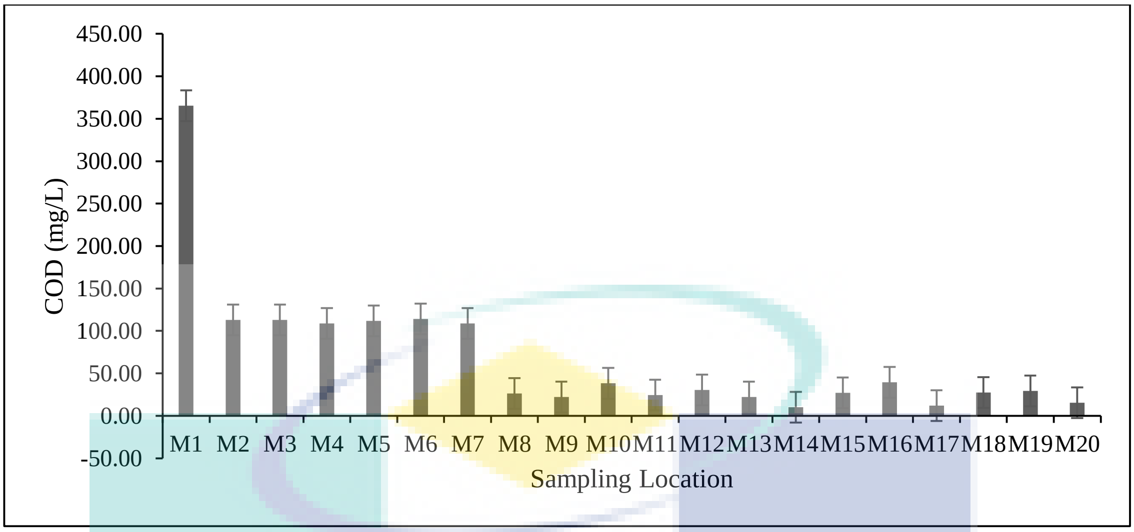


Figure 4.3 Mean of COD concentration at a sampling location (M1-M20) along Melaka River.

Based on the sampling time variation, Figure 4.4 shows the COD value fluctuated during S2. A higher level of COD was recorded mostly at downstream of Melaka River, shows that higher content of anthropogenic sources in the water bodies, where the station M1 shows the higher level of COD during S1 to S4. The high contribution of discharge from municipal waste, the use of chemical and organic fertilizer, has influenced the COD level (Al-Badaii et al., 2013). Shrestha and Kazama (2007) found that COD was insignificantly correlated with seasonal, due to the contribution of anthropogenic sources into the water bodies. The COD determine the number of organic pollutants in surface river water, which important to measure the water quality of the river (Othman et al., 2012).

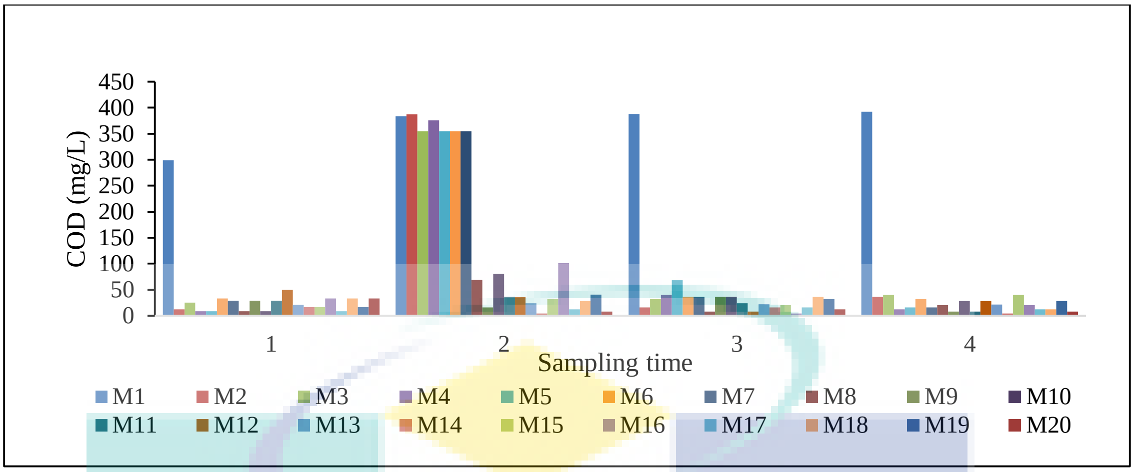


Figure 4.4 COD concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

4.2.2 Water quality assessment

On the other hands, the samples collected from the four times of water quality sampling (S1-S4) was also analysed for the physicochemical parameters to study the status of water quality parameter at Melaka River. Other parameters studied was pH, temperature, conductivity, total suspended solids (TSS), salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammoniacal nitrogen (NH_3-N), total nitrogen (TN), phosphate (PO_4^{3-}) and total phosphorus (TP). The results were divided into a physical parameter and a chemical parameter. The water quality assessment was important to determine the water quality status of the Melaka River, which further used in the TMDL implementation plan. The result of water quality sampling at tributaries (Putat River, Cheng River, and Durian Tunggal River) was attached at the appendix and not discussed in this chapter.

A descriptive statistic of physical parameters of surface river water was shown in Table 4.2, that explain the mean and standard deviation of the physical parameter (temperature, conductivity, salinity, and TSS) in the study area. The river cross section and river flow rate data were attached in the appendix.

Table 4.2 Mean and standard deviation of the physical parameter of surface water

Station	Temperature	Conductivity	Salinity	TSS
M1	28.15±0.25	4360.75±1582.40	34.41±16.63	203.08±197.39
M2	29.33±1.28	2445.70±2350.98	9.63±16.29	43.50±47.53
M3	29.73±2.45	2204.50±2234.42	9.44±16.40	41.50±32.61
M4	29.85±1.86	1950.30±2377.34	9.11±16.60	23.83±5.34
M5	30.48±1.66	1713.60±1981.29	9.14±16.59	39.75±40.37
M6	31.03±0.97	1833.85±1894.64	9.09±16.62	35.50±40.62
M7	30.90±1.15	1246.45±1635.20	8.83±16.78	44.17±34.66
M8	31.20±0.92	1704.88±2566.95	2.10±3.43	21.67±3.02
M9	30.80±0.63	430.85±177.39	0.40±0.14	20.25±4.92
M10	30.45±1.19	1083.73±1286.35	1.16±1.43	19.75±9.78
M11	29.58±1.40	1278.50±1832.08	1.67±2.50	30.42±23.45
M12	29.60±1.23	355.35±189.93	0.39±0.23	26.42±14.03
M13	30.80±0.80	282.90±51.38	0.32±0.06	35.27±26.32
M14	30.95±2.91	144.08±68.57	0.16±0.07	82.08±100.25
M15	31.68±2.22	108.43±7.38	0.15±0.04	40.04±17.43
M16	31.50±2.45	90.34±60.82	0.58±0.89	32.67±21.56
M17	30.40±2.01	121.80±17.49	0.13±0.02	41.19±27.21
M18	29.65±1.73	159.25±60.54	0.14±0.02	45.08±9.15
M19	30.13±3.45	112.24±25.24	0.11±0.03	94.42±66.70
M20	28.93±3.18	118.60±41.31	0.12±0.04	141.25±203.22

The conductivity for Melaka River was different between the downstream and upstream as shown in Figure 4.5. The average value of conductivity ranges from 90.34 µS/cm to 4360.75 µS/cm, the highest value recorded at M1, and the lowest value at M16. The NWQS for conductivity is below 1000 µS/cm for Class I and Class II (WEPA, 2006). The value of conductivity for freshwater is ranging from 10 µS/cm to 1000 µS/cm, while a higher value of conductivity indicates the rivers have been polluted (Al- Badaii et al., 2013). Besides, the conductivity also can be affected organic compounds such as oil and alcohol, the inorganic dissolved solids such as calcium and chloride, and also temperature (Al- Badaii et al., 2013). The wide range of conductivity occurs because the downstream part of Melaka River experiences the tidal interference twice daily, because the higher conductivity has been observed. The value of conductivity was higher at M1 due to the location of the sampling station near to the estuaries. During S2 and S3, the higher values of conductivity at the downstream, while on S1 until S4, the value of conductivity at the upstream were constantly low as shown in Figure 4.6. The conductivity was also affected by the concentration of salts, this proven at the M1, the salinity was higher, as well as the conductivity (Uqab et al., 2017).

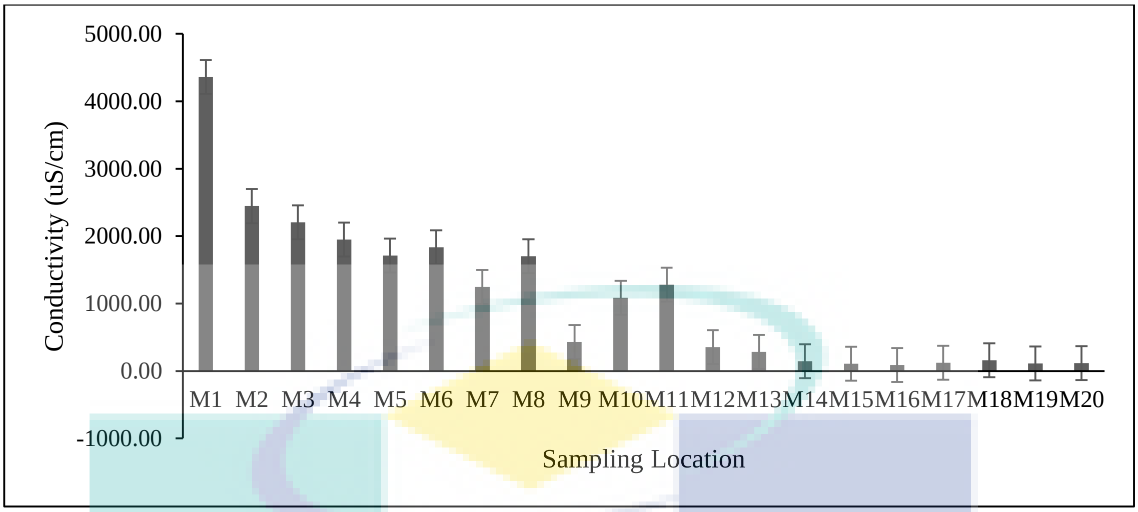


Figure 4.5 Mean of conductivity at a sampling location (M1-M20) along the Melaka River.

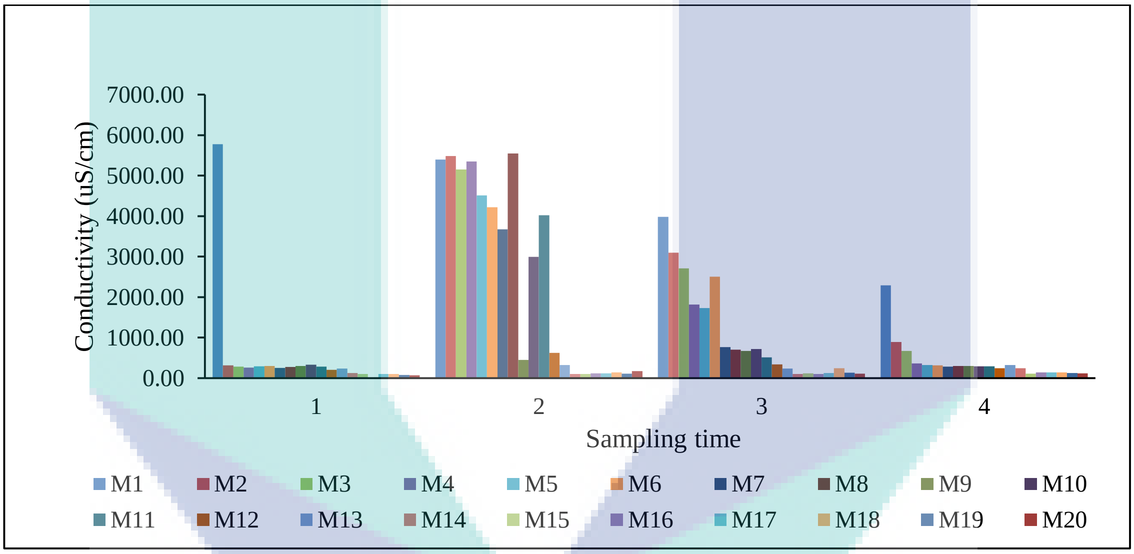


Figure 4.6 Conductivity value on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The average values of salinity were range from 0.11 ppt to 34.41 ppt along the Melaka River. The salinity values indicate the condition of river water at the Melaka River were freshwater to saltwater as shown in Figure 4.7. The salinity at M1, indicate the surface river water shows the properties of salt water, while the other locations show the values of slightly saltwater to the freshwater condition. This condition can occur because of the tidal effect, which was high tide and low tide (Aris et al., 2013). The salinity has an important role in physical mixing rates (Aris et al., 2013) that could be affected at the M1 sampling location. Based on sampling time variation, the salinity ranges from 0.0714 ppt to 49.05 ppt, whereas the highest and the lowest values were analysed during S3 as shown in Figure 4.8. The conductivity and salinity of Melaka River were higher at the downstream area (M1), which near to the sea, and lower at the upstream of the river. The conductivity and salinity of the river were significantly related to each other. However, the conductivity and salinity of Melaka River were widely varied, the downstream of the river shows the higher value of conductivity and salinity, while the lower value of conductivity and salinity observed at the upstream.

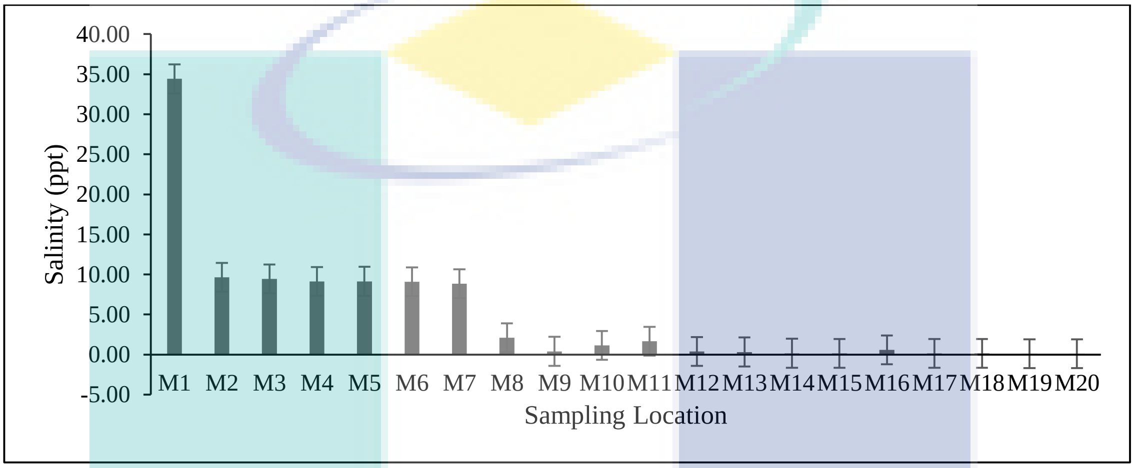


Figure 4.7 Mean of salinity at sampling location (M1-M20) along Melaka River.

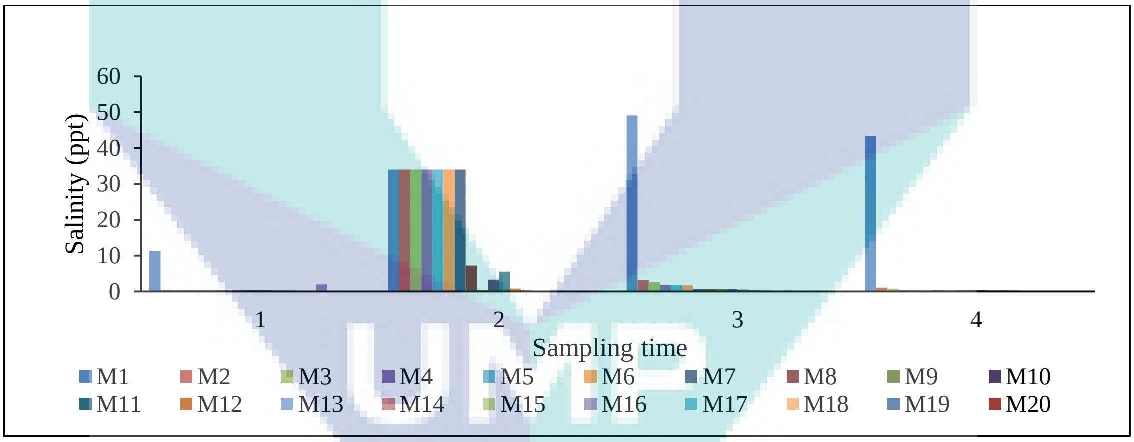


Figure 4.8 Salinity concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The Melaka River water temperature ranges from 28.15 °C to 31.68 °C as shown in Figure 4.9. The highest mean of temperature was recorded at M15, while the lowest mean of temperature was recorded at M1. The mean of temperature shows the small range of differences among the sampling stations. The downstream of Melaka River, located near to the Melaka Straits, was observed to have lower temperature due to the tidal flow. Based on Figure 4.10, the river temperature was higher at M15 (34.7 °C) during S1, and the lowest temperature recorded at M20 (26.0 °C) at S4. The value of temperature during the sampling was within the acceptable range and not widely varied. The time of sampling and weather condition also contribute to the value of temperature during the sampling (Hamid et al., 2016). The overall trend of water temperature is found to be very similar during the sampling time variation. The temperature is usually affected by other factors such as the location of sampling and time of sampling, which simultaneously will affect the concentration of dissolved oxygen, biological activities and others parameter (Al-Badaii et al., 2013).

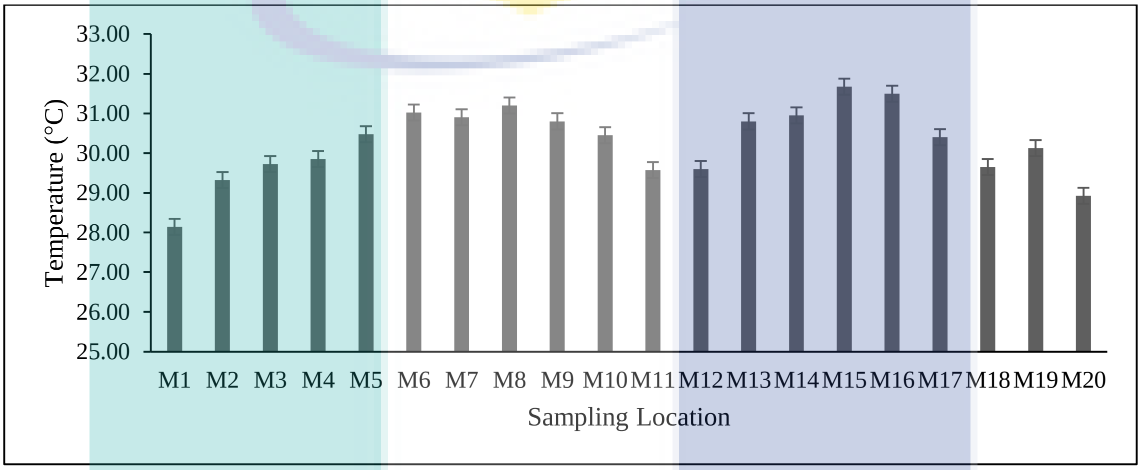


Figure 4.9 Mean of temperature at a sampling location (M1-M20) along Melaka River

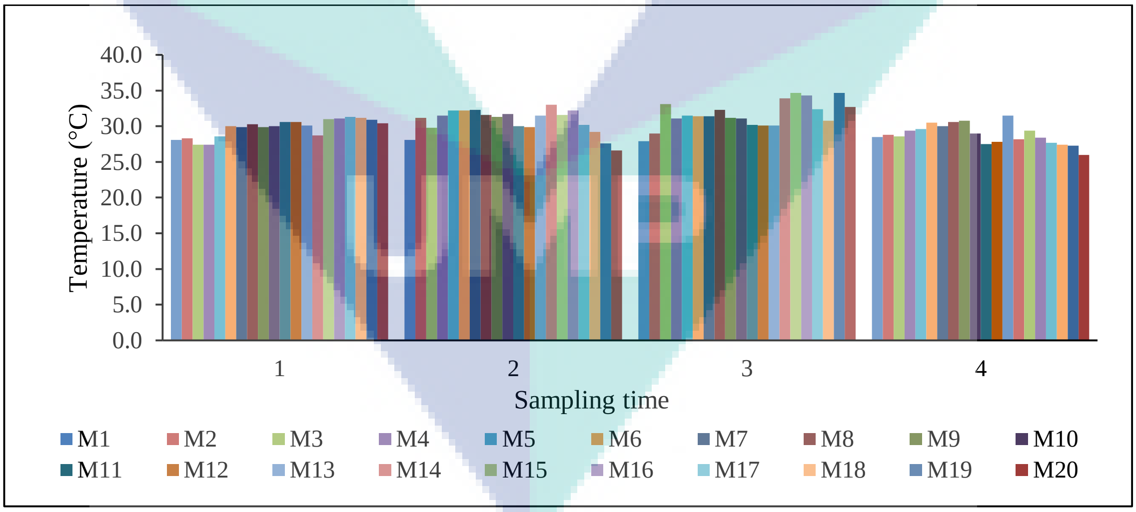


Figure 4.10 Temperature on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The TSS average value was range from 19.75 mg/L to 203.08 mg/L along the Melaka River. The highest mean value of TSS was at M1, and the lowest TSS value was at M10 as shown in Figure 4.11. The NWQS for Malaysia indicates the TSS value for Class II is 50 mg/L (WEPA, 2006). The value of TSS at M1 (203.08 mg/L) belonged to the Class IV water quality standard. According to the sampling time variation, the M1 shows the higher level of TSS on S2, S3 and S4, while on S1, the highest value of TSS was recorded at the M20 as shown in Figure 4.12. The lowest value of TSS was found at M10 during S1 sampling time. Higher mean and standard deviation of TSS can determine the common sources of origin of the chemical parameter, which shows the anthropogenic impact on the water quality (Shrestha & Kazama, 2007). The higher value of TSS can be contributed by the soil erosion due to human activities and rainy days (Al-Badaii et al., 2013).

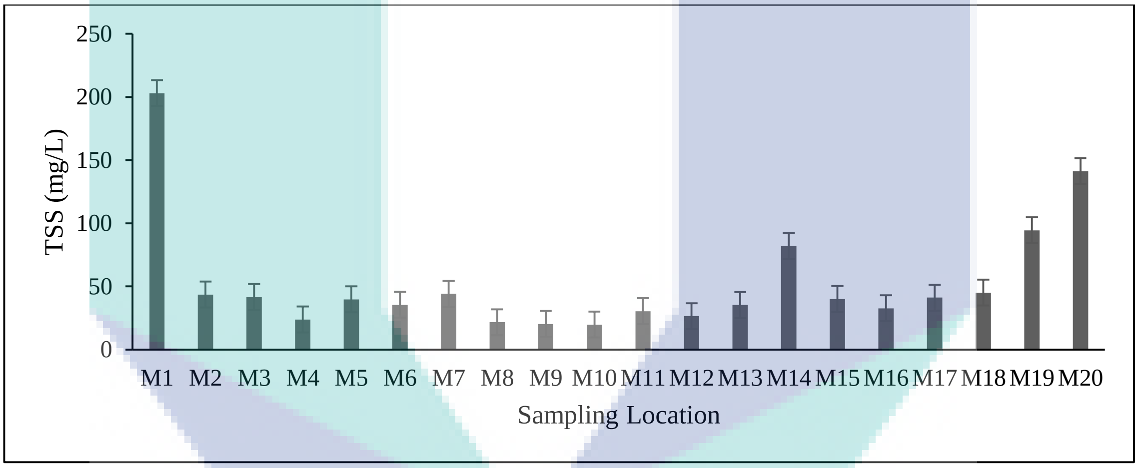


Figure 4.11 Mean of TSS at a sampling location (M1-M20) along Melaka River.

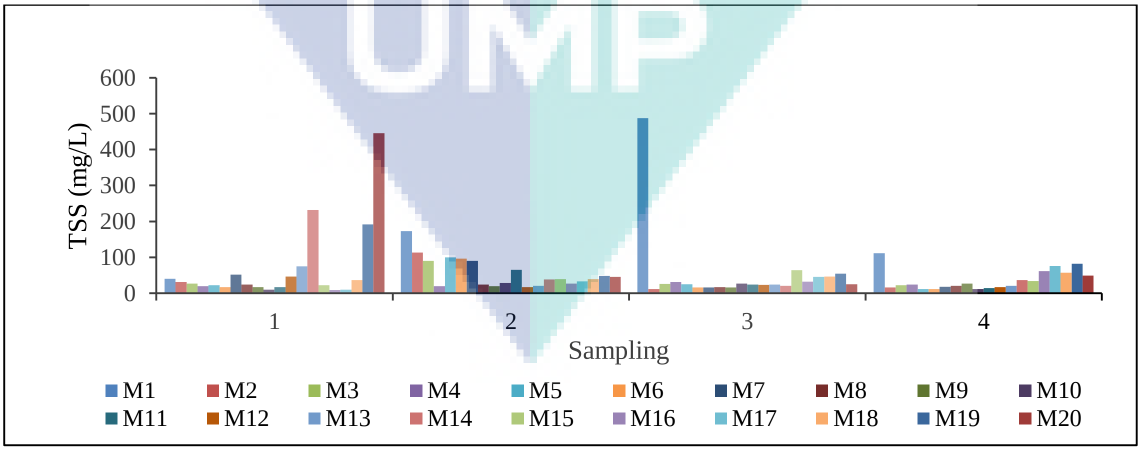


Figure 4.12 TSS concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The mean and standard deviation of the chemical parameter for DO, BOD, COD, and pH parameters was shown in Table 4.3. The concentration of DO and BOD were significantly related to another, where the mean of DO was relatively higher than BOD, as the increase of DO, should decrease the concentration of BOD. The pH was categorised under the chemical parameter due to the Infowork RS properties. The COD concentration was discussed in above subchapter 4.2.1.

Table 4.3 Mean and standard deviation of a chemical parameter of surface water.

Location	DO (mg/L)	BOD (mg/L)	pH	COD (mg/L)
M1	7.59±3.65	6.80±3.88	6.59±0.58	365.54±44.66
M2	4.96±2.51	6.50±3.87	7.21±0.41	112.89±183.10
M3	5.12±2.06	5.80±4.03	7.28±0.68	112.94±161.39
M4	5.82±2.53	5.88±3.47	7.43±0.83	108.95±178.26
M5	5.58±3.54	4.40±2.75	7.55±0.85	111.79±164.19
M6	5.30±2.69	5.10±3.21	6.95±0.18	114.01±160.56
M7	5.41±4.80	9.58±5.03	7.41±0.94	108.97±164.12
M8	3.51±2.01	12.73±7.90	6.31±1.24	26.21±28.77
M9	3.19±0.50	8.40±5.08	6.72±0.28	22.30±12.59
M10	2.59±0.30	9.48±6.36	6.17±1.32	38.24±30.58
M11	4.19±0.67	13.00±11.11	6.10±1.34	24.34±12.00
M12	4.14±1.88	8.25±6.05	6.19±1.15	30.34±17.42
M13	8.04±2.62	12.65±2.22	5.36±1.38	22.21±1.48
M14	5.54±1.39	7.20±3.03	7.32±0.38	10.16±7.10
M15	5.17±0.94	6.73±2.89	6.29±2.01	27.22±10.86
M16	4.79±0.63	14.45±8.91	6.57±1.52	39.50±42.58
M17	5.03±0.83	12.50±6.60	7.61±0.42	12.103.14
M18	5.56±1.80	12.30±11.51	7.47±0.34	27.36±10.73
M19	5.11±1.30	13.38±11.62	7.31±0.41	29.23±9.86
M20	6.98±2.40	12.18±8.24	7.81±1.11	15.28±12.09

These parameters show the health of the river in the overall situation such as DO was among the most important water quality parameter in determining the water quality status of the river. According to the DOE water quality standard, the good water quality condition of the river for DO should be higher than 7 mg/L. However, enough amount of DO for water aquatic life was 5 mg/L, while less than 3 mg/L, the aquatic life was suffered. The highest average value of DO was recorded at M13, and the lowest value of DO was recorded at M10. The Figure 4.13 shows the value of DO at M2, M8, M9, M10, M11, M12, and M16 were below than the threshold value of NWQS standard, between 5-7 mg/L for Class II. The lower DO value at M10 may due to the contribution of anthropogenic sources, from the shop lot discharge into the river. Uqab et al. (2017) reported that lower value of DO indicates the process of bioaccumulation, and bacterial decomposition of organic matter activity, while the higher DO value shows the good aeration condition at the location. The lower DO values indicate that the DO is consumed by the degradation of organic matter (Al-Badaii et al., 2013). Hossain et al. (2014) indicates the high organic and inorganic loads can be caused to the low DO. The sampling time variation among the sampling location shows that the value of DO at all sampling point during S1 and S4 at several sampling points was below 5 mg/L, except at M1, M4, M13, M14, M15, M16, M17, M18, M19, and M20. While during the S2, the DO level was below than 5 mg/L at M9, M10 and M11. The value of DO during S3 at M7, M8, M9, M10, M11, M12, and M19, was less than 5 mg/L. The DO values were varied over the sampling time as shown in Figure 4.14.

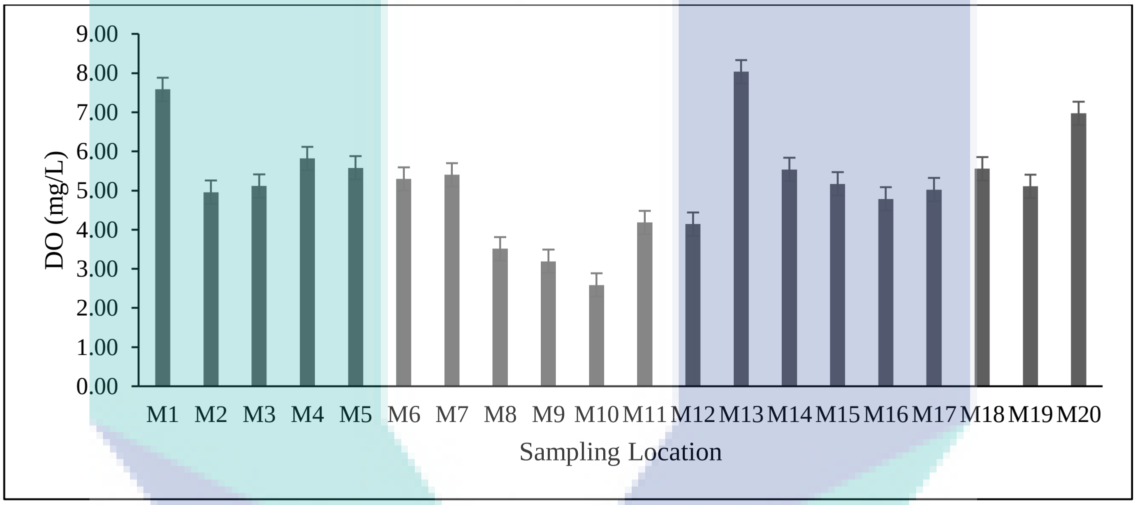


Figure 4.13 Mean of DO at a sampling location (M1-M20) along the Melaka River.

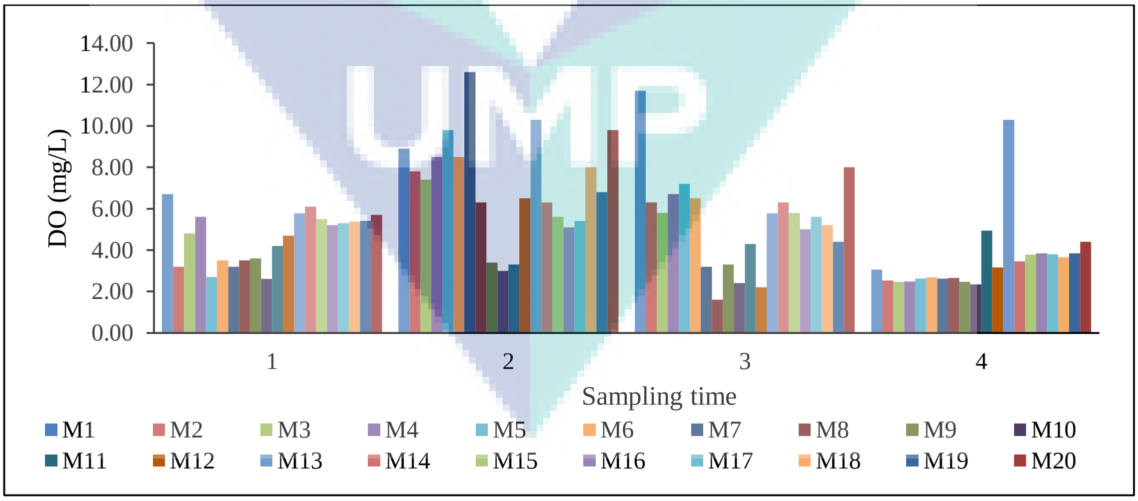


Figure 4.14 DO concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The BOD along Melaka River was above the acceptable range, which was 3.0 mg/L for Class II according to the NWQS threshold level as shown in Figure 4.15. The BOD value was range from 4.40 mg/L to 14.45 mg/L. The highest value of BOD was recorded at M16, while the lowest value of BOD was found at M5. The sources of pollution at M16 may come from the decomposition of organic matter from agricultural runoff since there were agricultural activities occurs at M16. The increasing of nutrient into the river such as from the fertilizer and animals farm, can cause to the increase of BOD level (Al-Badaii et al., 2013).

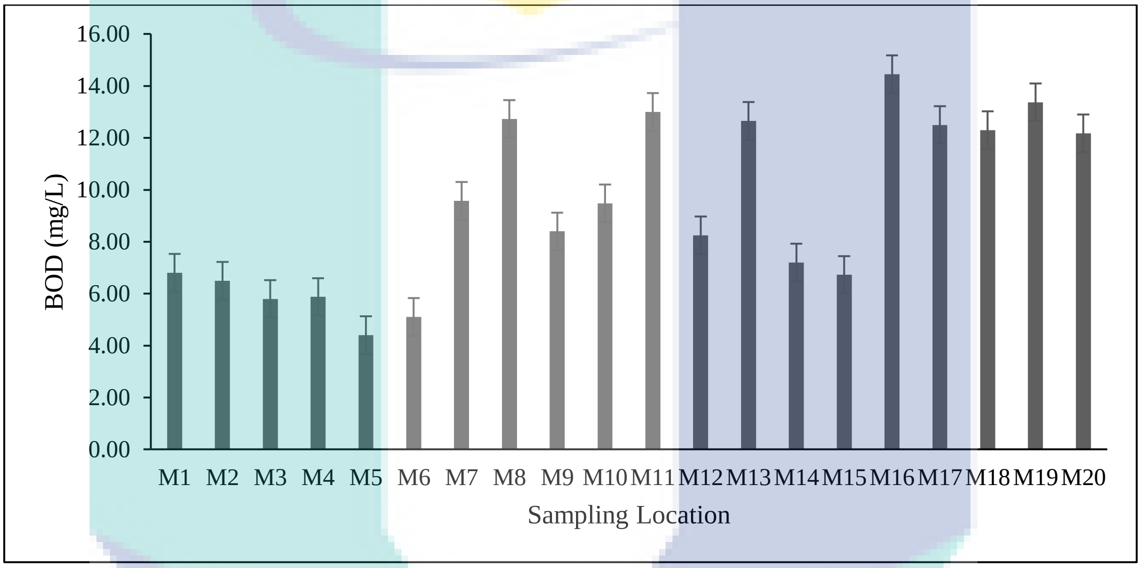


Figure 4.15 Mean of BOD at a sampling location (M1-M20) along the Melaka River.

The sampling time variation of BOD shows that all the values of BOD during S1 and S2 were above 3.00 mg/L as shown in Figure 4.16. However, during S3, the BOD value was less than 3.00 mg/L at M5 and M6. In contrast, during the S4, there was only one location (M13) shows the BOD value higher than the acceptable range, while the rest of sampling location indicates the BOD value less than 3.00 mg/L. BOD was measured the amount of oxygen used by aerobic microbes in water to perform the degradable of the organic material process (Wu et al., 2014).

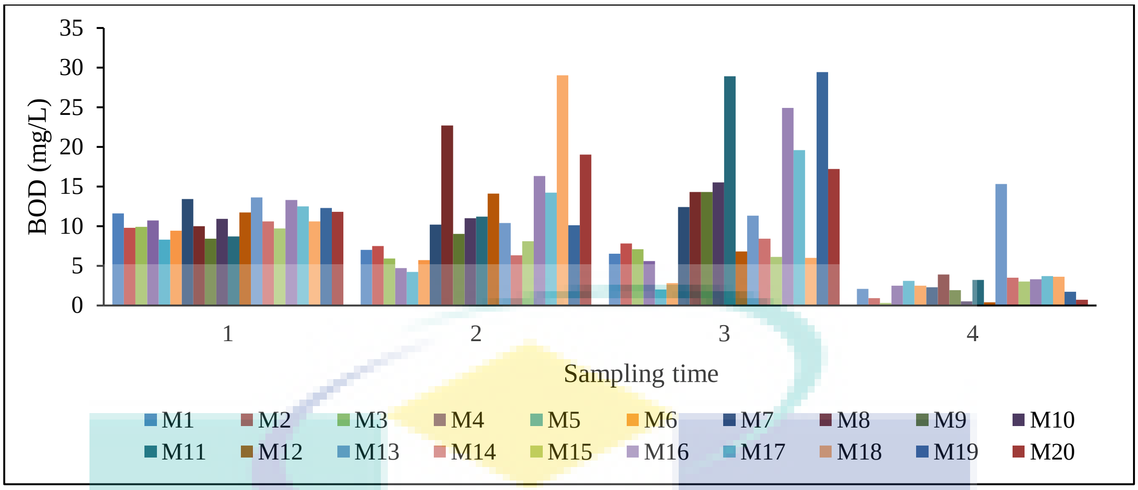


Figure 4.16 BOD concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The pH values at the Melaka River were range from 5.86 to 7.81, the acidic to alkaline condition was as shown in Figure 4.17. The pH parameter shows the properties of slightly acidic to neutral condition of surface river water. The pH at Melaka River was not within the acceptable limit of National Water Quality Standard (NWQS) for Malaysia, which is ranging from 6-7 for Class II (WEPA, 2006). The acidic condition was obtained at the downstream area (M8-M13), which caused by the contribution of anthropogenic sources from the tributaries (Shrestha & Kazama, 2007). At M8 to M13 stations, there was the contribution of two tributaries into the Melaka River, which was Putat River and Cheng River. These two rivers were flowing into the Melaka River and gave the significant contribution of pollution sources into the river.

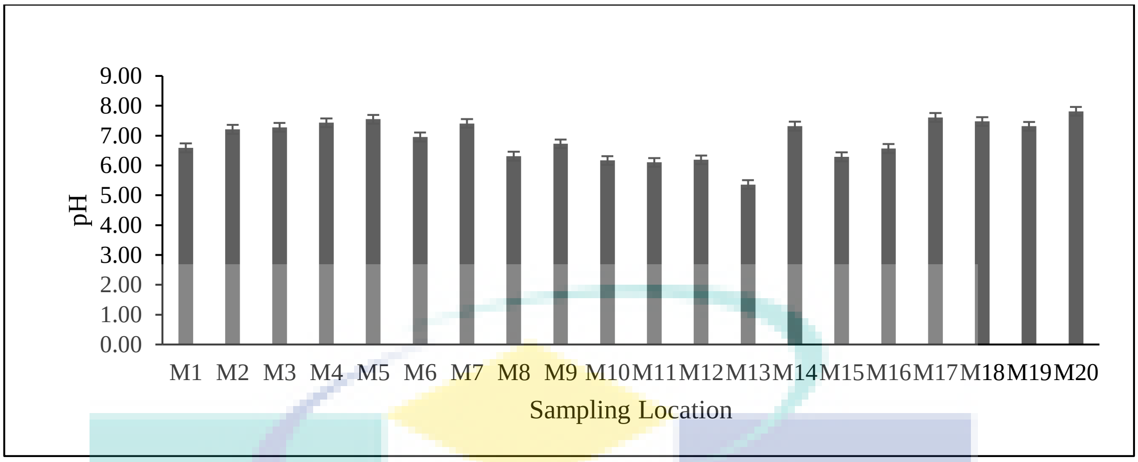


Figure 4.17 Mean of pH concentration at a sampling location (M1-M20) along the Melaka River.

The pH of the Melaka River was also studied based on the sampling time variation from S1-S4, shows the pH value ranged from 3.29 to 9.46, where the highest and the lowest values were analysed during S2. The value of pH during S1, S3, and S4 ranged from 6.44 to 7.84, indicating the slightly acidic to neutral pH of water condition. However, the value of pH during S2 was varied into a wide range of water condition as shown in Figure 4.18. The preservation of pH of the river was important for the aquatic life, whereas the high value of pH can cause to the natural disturbance (Al- Badaii & Suhaimi-Othman, 2014).

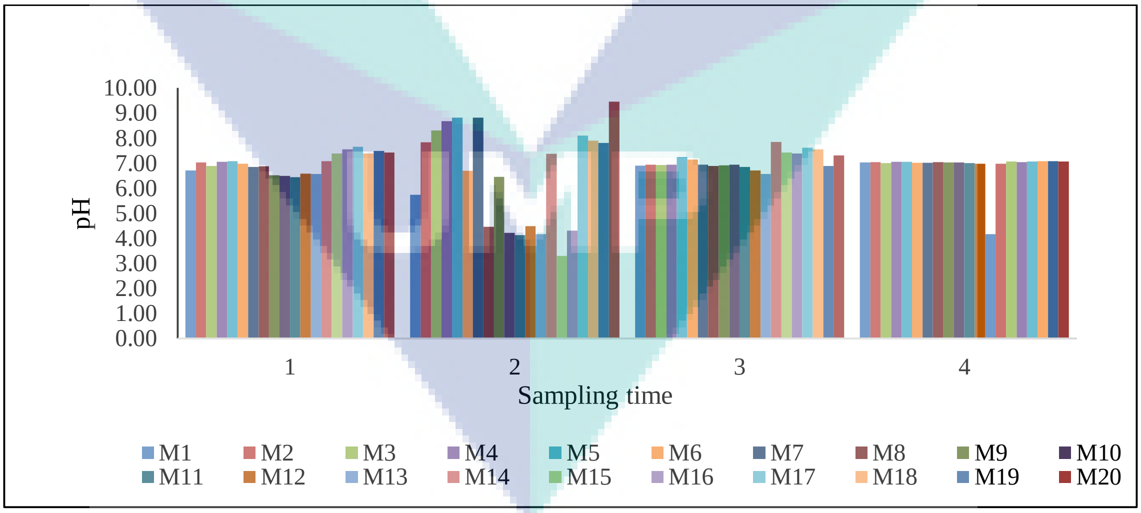


Figure 4.18 pH concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

Other chemical parameters are NH_3-N, TN, PO_4^{3-} and TP. The mean values of the chemical parameter along the Melaka River were shown in Table 4.4. The mean of NH_3-N, TN, PO_4^{3-} and TP was higher at all stations which mainly caused of the domestic waste, industrial effluent and agricultural runoff from the nearest area to the sampling location (Muyibi et al., 2008).

Table 4.4 Mean and standard deviation of the chemical parameter at Melaka River.

Location	NH_3-N (mg/L)	TN (mg/L)	PO_4^{3-} (mg/L)	TP (mg/L)
M1	2.62±2.83	0.5039±0.21	0.3222±0.14	1.4936±1.79
M2	6.96±8.08	0.2483±0.07	0.2374±0.08	0.4187±0.10
M3	7.11±8.02	0.3348±0.21	0.2120±0.04	0.6844±0.61
M4	7.20±8.22	0.2267±0.12	0.1683±0.10	0.4026±0.09
M5	12.87±15.80	0.3183±0.04	0.2068±0.07	0.6602±0.36
M6	12.34±14.05	0.2525±0.08	0.1769±0.06	0.4509±0.20
M7	7.86±8.96	0.3163±0.11	0.2432±0.09	0.4750±0.19
M8	10.54±12.51	0.2977±0.17	0.1960±0.13	0.4750±0.29
M9	7.79±11.30	0.2504±0.11	0.1739±0.10	0.7287±0.64
M10	9.60±14.31	0.2916±0.21	0.9564±1.44	1.5378±1.38
M11	9.99±11.65	0.2998±0.08	0.2932±0.21	1.0024±0.69
M12	4.83±9.41	0.2813±0.10	0.7465±0.98	1.0547±0.90
M13	0.14±0.05	0.1486±0.01	0.3305±0.11	0.4240±0.08
M14	2.75±3.02	0.4623±0.43	0.1578±0.11	0.4187±0.24
M15	3.74±4.05	0.6640±0.30	0.3572±0.16	1.6506±0.50
M16	3.54±5.24	0.3636±0.20	0.1992±0.05	0.7408±0.68
M17	3.47±5.11	0.4212±0.23	0.2748±0.08	0.9179±0.83
M18	4.73±6.27	0.5519±0.17	0.2086±0.05	1.6317±2.10
M19	3.91±4.14	0.5817±0.16	0.3395±0.22	0.9823±0.67
M20	0.90±0.95	0.3523±0.18	0.2596±0.19	0.7609±0.82

NH_3-N was part of inorganic nitrogen and able to be absorbed by the plant. The range of NH_3-N was from 0.14 mg/L to 12.87 mg/L, where the highest value at M5, and the lowest value at M13 as shown in Figure 4.19. M5 located at a downstream area with high industrial and tourism activities occurs. This show that there is a significant contribution of industrial waste into the river (Al- Badaii & Suhaimi-Othman, 2014). The NWQS for Malaysia indicates the values of NH_3-N for Class II is 0.3 mg/L. The analysis shows that most sampling location has higher values of NH_3-N which belong to the Class IV and Class V of water quality standard, except for M13. The sources pollution of NH_3-N usually came from wastewater and organic matter decomposition (Santhi et al., 2006). Besides, the domestic waste such as sewage treatment plant and surface runoff the urban areas also contribute to the NH_3-N (Nasir et al., 2011). The value of NH_3-N was observed significantly low during the S1 and S2. However, the NH_3-N concentration significantly increased during S3 and S4 as shown in Figure 4.20. The variation of NH_3-N might significant to the impact of the wet and dry season.

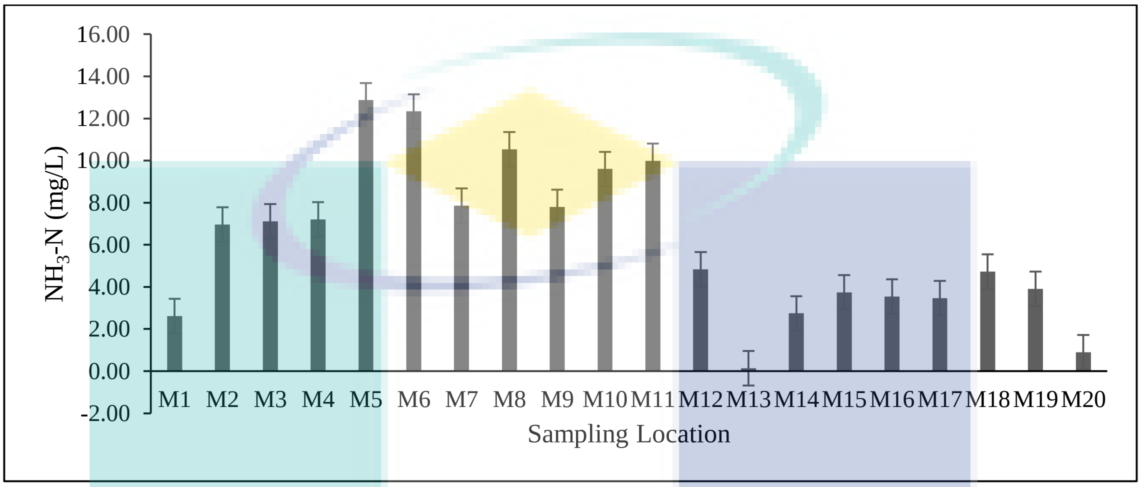


Figure 4.19 Mean of NH_3-N at a sampling location (M1-M20) along the Melaka River.

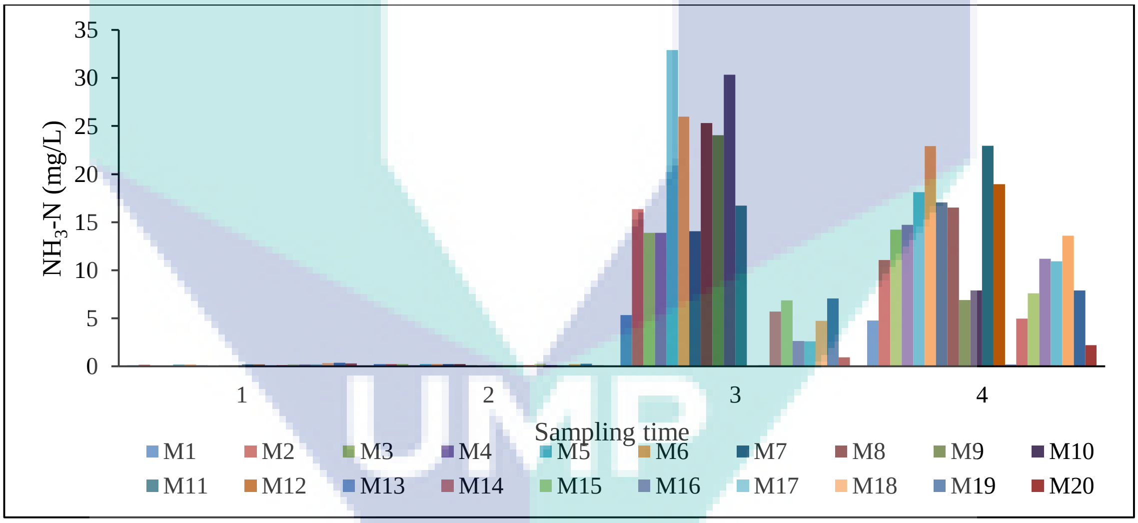


Figure 4.20 NH_3-N concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

Figure 4.21 indicates the spatial variation of TN values along the Melaka River. TN along the Melaka River was range from 0.15 mg/L to 0.66 mg/L. The highest concentration of TN was recorded at M15, while the lowest concentration of TN was found at M13. The downstream show the lower value of TN excepts at M1, compared to the upstream shows the higher value. TN varied during the wet and dry season due to the runoff from agricultural activities might affect the amount of TN enters the river. The concentration of TN shows the differences during every time of sampling. The higher value of TN was found during the S1 at M14, while the other sampling point shows the lower value of TN. The level of TN increases from S1 to S4 as shown in Figure 4.22.

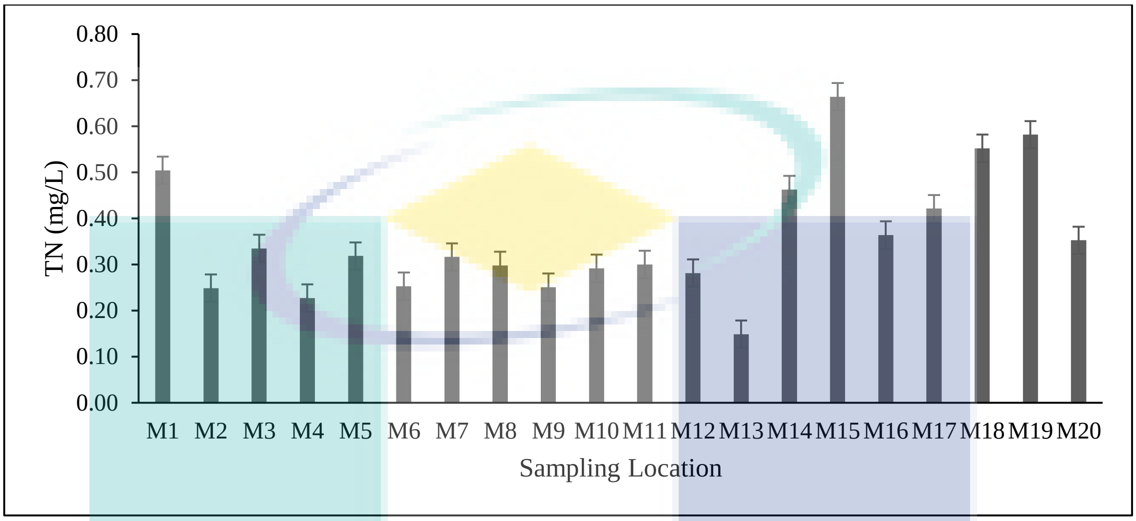


Figure 4.21 Mean of TN at a sampling location (M1-M20) along the Melaka River.

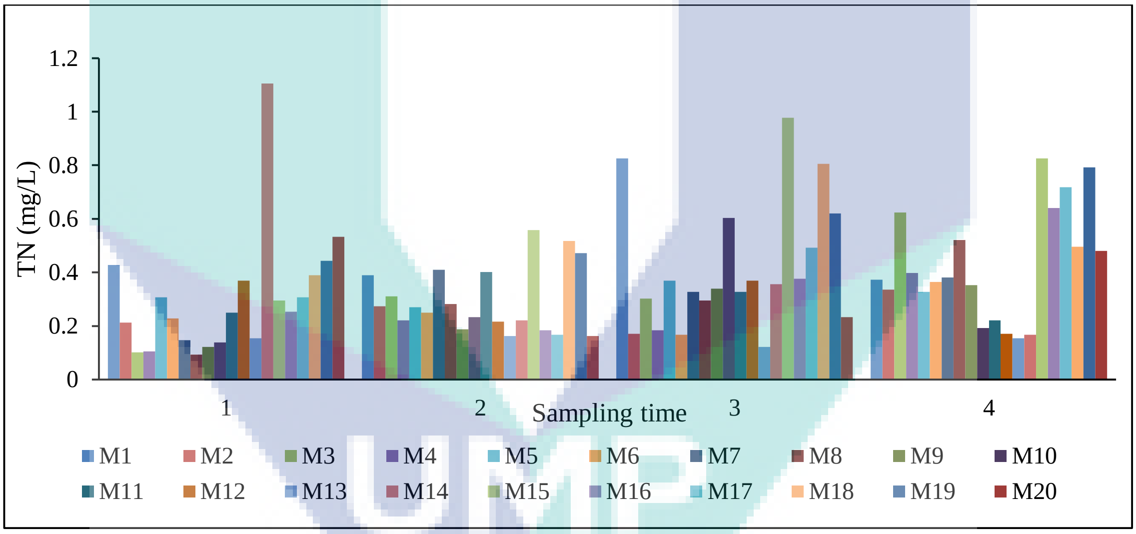


Figure 4.22 TN concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

PO_4^{3-} is a form of phosphorus and absorbable by plants (Widyastuti & Haryono, 2016). PO_4^{3-} occurs very less than any other element, with a natural concentration in surface water is 0.005-0.02 mg/L. Figure 4.23 shows that the higher value of PO_4^{3-} at M10 and M12, while the lowest value of PO_4^{3-} at M14. The value of PO_4^{3-} range from 0.16 mg/l to 0.96 mg/l. The trend of PO_4^{3-} similar for each sampling sites except for M10 and M12. The location of M10 which near to the industrial areas might affect the value of PO_4^{3-}. The higher effluent from the industrial areas may contain detergents, and industrials wastewater has a significant contribution to the higher value of PO_4^{-3} (Al-Badaii et al., 2013). The variation of PO_4^{-3} may significant to the impact of raining and sunny day (Santhi et al., 2006). Samsudin et al. (2017) found that the nitrogenous fertilizer from the agricultural runoff can increase the concentration of NH_3-N and PO_4^{3-}. Besides, the anthropogenic sources from industrial and domestic waste also contributed to PO_4^{3-} pollution. Figure 4.24 shows the PO_4^{3-} value based on sampling time variation at 20 sampling stations along the Melaka River. The higher value of PO_4^{3-} was recorded during S2, at M10 and M12. The PO_4^{3-} were lower than 1.00 mg/L during S1 to S4 except for M10 and M12 during S2. The lowest value of PO_4^{3-} was recorded at M4 during S2.

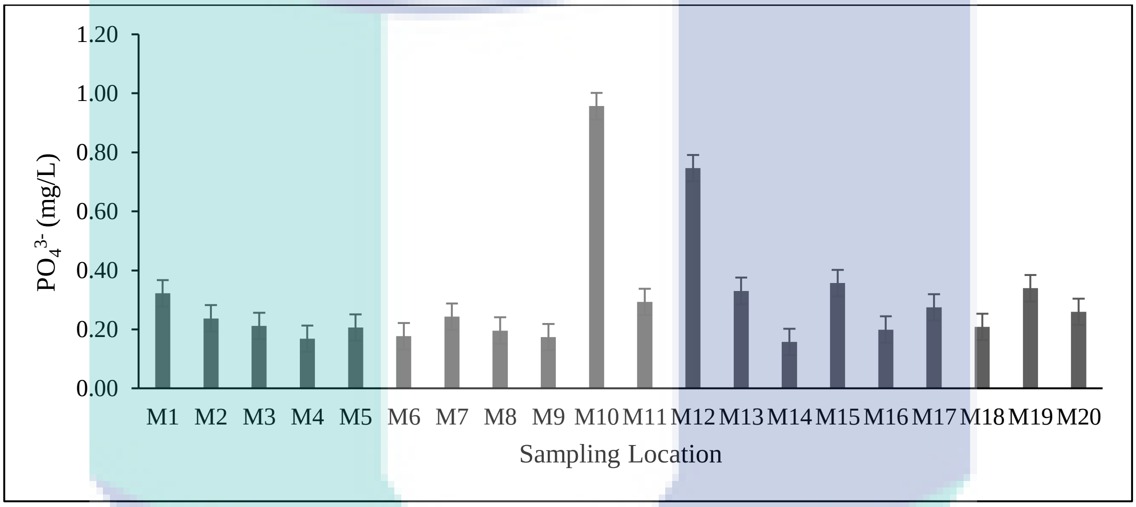


Figure 4.23 Mean of PO_4^{3-}at a sampling location (M1-M20) along the Melaka River.

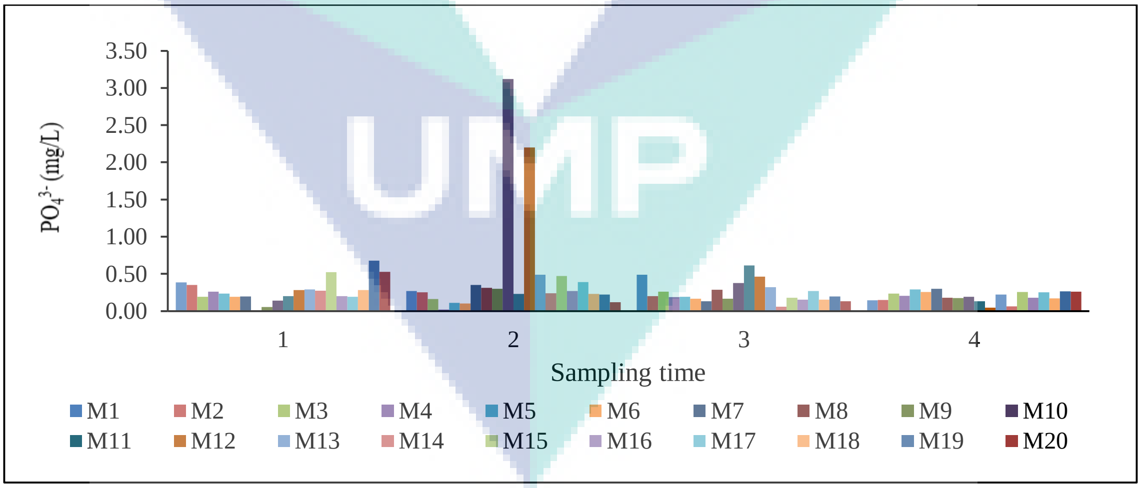


Figure 4.24 PO_4^{3-}concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

The TP value range from 0.40 mg/L to 1.65 mg/L at the Melaka River is as shown in Figure 4.25. The higher value of TP was found at M15, and the lowest value of TP was observed at M4. The higher value of TP shows the strong contribution of agricultural runoff from the nonpoint sources (Hamid et al., 2016) since M15 is located near to the paddy field area. Besides, the M1, M10, and M18 also show a higher value of TP. The M1 and M10 were located near to the domestic and industrial area, which shows the contribution of pollution from the point sources (Hamid et al., 2016). While M18 was located at the palm estates area that significant contribution of fertilizer runoff from the agricultural areas. The value of TP was widely varied among the sampling location based on the pollution sources enter the water bodies near the sampling location. According to Figure 4.26, TP value based on sampling time variation shows the higher value during S3, at M18 and M1. The lowest value of TP was recorded at M3 during S1. The value of TP was varied along the sampling location. Therefore, the seasonal variation also affected the value of TP (Qian et al., 2007)

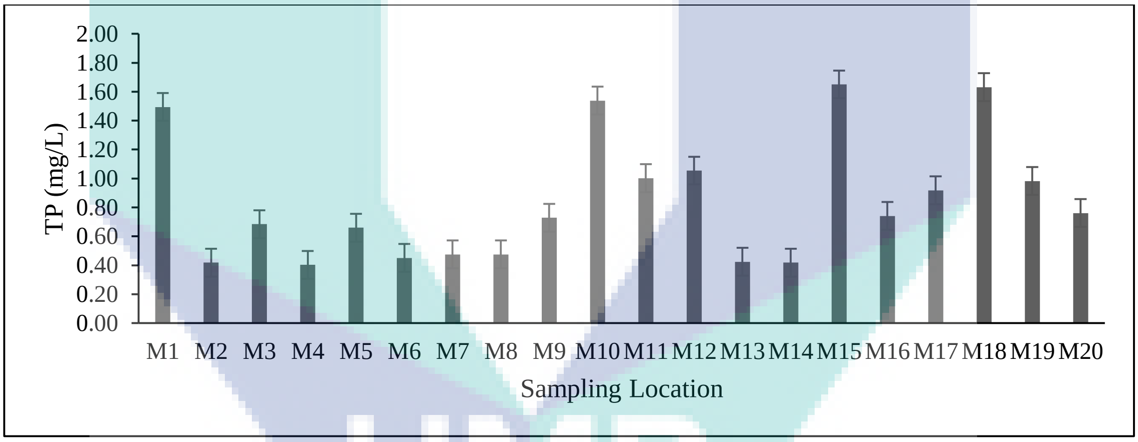


Figure 4.25 Mean of TP at sampling location (M1-M20) along Melaka River.

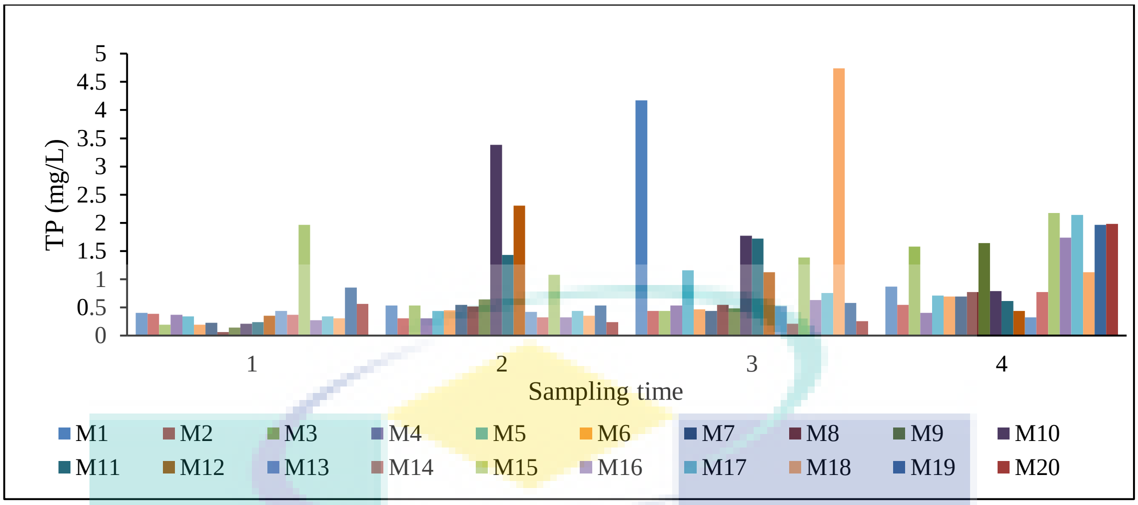


Figure 4.26 TP concentration on 21st August 2014 (S1), 6th September 2014 (S2), 20th September 2014 (S3), and 3rd October 2014 (S4), at M1-M20 of sampling location along Melaka River.

4.3 Pearson Correlation Coefficient Analysis

Pearson correlation coefficient analysis was done to determine the correlation among physicochemical parameter to identify the sources of pollution that enter the water bodies. Besides, the correlation analysis was important during TMDL development. The correlation analysis provided the correlation among the water quality parameters, such as the improvement of the COD parameter can affect the other parameters that correlated with COD. The data shows the physicochemical parameter properties whether correlated positively or negatively significant. The positive correlation indicates the similar sources of origin and similar contamination trend, while a negative correlation indicates the opposite nature of sources. The strong significant correlation occurs at p-value 0.01 and 0.05. The correlation analysis for Melaka River was done during S1 to S4 as shown in Table 4.5-4.8.

Table 4.5 Pearson correlation coefficient analysis of water quality parameter at Melaka River during S1.

	pH	DO	PO_4^{3-}	TP	COD	BOD	NH_3-N	TN	TSS
pH	1								
DO	0.356	1							
PO_4^{3-}	**0.461***	**0.520***	1						
TP	0.392	0.360	**0.703****	1					
COD	-0.208	0.419	0.177	-0.027	1				

BOD	0.271	0.430	0.255	0.013	0.134	1			
NH_3-N	**0.586****	0.202	**0.641****	0.329	-0.121	0.077	1		
TN	0.297	0.499*	0.402	0.174	0.147	0.082	0.363	1	
TSS	0.304	0.389	**0.566****	0.160	-0.031	0.241	0.434	**0.621****	1

Table 4.6 Pearson correlation coefficient analysis of water quality parameter at Melaka River during S2.

	pH	DO	PO_4^{3-}	TP	COD	BOD	TN	NH_3-N	TSS
pH	1								
DO	**0.533***	1							
PO_4^{3-}	**-0.451***	-0.383	1						
TP	**-0.530***	**-0.508***	**0.940****	1					
COD	0.405	0.520*	-0.253	-0.246	1				
BOD	-0.109	-0.089	0.075	-0.004	**-0.545***	1			
TN	-0.079	0.058	-0.160	0.005	0.056	0.114	1		
NH_3-N	0.229	0.364	-0.420	-0.390	0.421	-0.063	**0.697****	1	
TSS	0.269	0.413	-0.290	-0.230	**0.740****	-0.405	0.293	**0.530***	1

Table 4.7 Pearson correlation coefficient analysis of water quality parameter at Melaka River during S3.

	pH	DO	PO_4^{3-}	TP	COD	BOD	TN	NH_3-N	TSS
pH	1								
DO	0.240	1							
PO_4^{3-}	**-0.551***	-0.048	1						
TP	0.100	0.299	0.368	1					
COD	-0.150	**0.669****	0.376	**0.606****	1				
BOD	-0.073	-0.325	0.219	-0.180	-0.230	1			
TN	0.323	0.144	0.115	**0.696****	0.412	-0.001	1		
NH_3-N	-0.202	-0.254	0.002	-0.124	-0.049	-0.189	-0.193	1	
TSS	-0.089	**0.657****	0.393	**0.622****	**0.975****	-0.140	**0.505***	-0.213	1

Table 4.8 Pearson correlation coefficient analysis of water quality parameter at Melaka River during S4.

	pH	DO	PO_4^{3-}	TP	COD	BOD	TN	NH_3-N	TSS
pH	1								
DO	**-0.903****	1							
PO_4^{3-}	-0.047	0.025	1						
TP	0.309	-0.089	0.402	1					
COD	0.049	-0.083	-0.169	-0.075	1				
BOD	**-0.922****	**0.886****	0.082	-0.253	-0.081	1			
TN	0.336	-0.175	**0.529***	**0.827****	-0.021	-0.211	1		
NH_3-N	0.404	-0.423	-0.013	-0.352	-0.237	-0.320	-0.080	1	
TSS	0.146	0.045	0.002	**0.511***	**0.608****	-0.052	**0.485***	**-0.451***	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

According to the correlation matrix calculated by using SPSS software, during four times sampling, there was a significant correlation occurs between each parameter. During S1 and S2, there was a strong positive significant correlation between PO_4^{3-} and TP, with r-value 0.703 and 0.940, respectively. The same situation also predicted in the study of water quality monitoring done by Kim et al. (2009). In S1, there was a strong significant correlation between PO_4^{3-} and NH_3-N (r-value: 0.641), and between TSS and TN (r-value: 0.621). The strong significant positive correlation shows the similar sources of origin and similar contamination trend that occurs at p-value 0.01 or 0.05. The COD shows the negative correlation with pH (r-value: -0.208), TP (r-value: -0.27), TSS (r-value: -0.31), and NH_3-N (r-value: -0.121). The negative correlation shows that the value of one parameter decrease, while another value of the parameter was increased. There was strong positive significant correlation relationship between TP and PO_4^{3-} (r-value: 0.940), TN and NH_3-N (r-value: 0.697), and between COD and TSS (r-value: 0.740) occurs during S2. Negative significant correlation relationship occurs between pH and PO_4^{3-} (r-value: -0.451), pH and TP (r-value: -0.530), DO and TP (r-value: -0.508), and COD and BOD (r-value: -0.545). The negative relationship between COD and BOD indicates the properties of BOD as the extent of biodegradable organic matters and needed of oxygen for this process (Kamble & Vijay, 2011), while COD has its own properties which were the indicator of organic wastes (Othman et al., 2012).

The strong significant correlations also appear between COD and DO (r-value: 0.699), TSS and DO (r-value: 0.657), COD and TP (r-value: 0.606), TP and TN (r-value: 0.696), TP and TSS (r-value: 0.622), and COD and TSS (r-value: 0.975) during S3. All this relationship among the organic factor represents the contribution of point sources, such as discharge from domestic waste, wastewater and industrial effluent (Shrestha & Kazama, 2007). However, only three strong significant correlation occurs during S4, between DO and BOD (r-value: 0.886), TP and TN (r-value: 0.827), and COD and TSS (r-value: 0.608). A study done by Shrestha and Kazama (2007), proved the relationship between COD and TSS, indicates the erosion effect and associated organic matter. The strong significant correlation occurs with the p-value is 0.01, where the linearly significant correlation between two variables, and H_0 hypothesis (There no correlation occurs between two variables) was rejected. The smaller the p values, the better. The r value indicates the strength and direction (+/-) relationship of the correlation, and the bigger the value was better. Based on the correlation analysis done for S1, S2, S3 and S4, there was variation occurs among types of variables. The variation between different two variables may occur because of the water flow due to rainfall (Bhuiyan et al., 2011). There was many of correlation occurs during S1 and S2, compared to numbers of correlation occurs during S3 and S4, because of a heavy raining event especially during S4, while no rainfall events happen during S1 and S2. The correlation becomes weaker during the raining season compared to the dry season (Kim et al., 2009). The high flow of water due to rainfall events was shown in the relationship between TSS and COD, TSS and DO, and DO and COD.

Besides, the correlation between COD and nutrients, such as TP and TN, indicates the presence of the high load of organic pollution from the industrial and domestic wastewater (Kamble & Vijay, 2011), where the concentration of COD was increased. Besides, the correlation between COD and TP shows the same origin of the organic compound (Kozaki et al., 2017). COD is one of the indicators in determining the contamination with organic waste (Othman et al., 2012). Furthermore, the occurrence of relationship TN, TP, PO_4^{3-} and NH_3-N with DO, indicates the high nutrient content in the river, increase the level of DO, caused by the photosynthesis process occur (Kamble & Vijay, 2011). The correlation between TP and PO_4^{3-}, NH_3-N and TN describe the cycles of nitrogen and phosphorus.

The correlation between PO_4^{3-} and TSS related to the properties of non-soluble and adsorptive phosphorus where it behaves with soil particles (Kim et al., 2009). It is proved with increasing the amount of TSS, the concentration of PO_4^{3-} linearly increased. A study done by Kim et al. (2009), shows that TSS and PO_4^{3-} belong to the same group in cluster analysis. Furthermore, the correlation between TN and TSS shows the relationship between TSS as the carrier of nitrogenous pollutants (Yu et al., 2016), when the value of TSS higher, the concentration of TN increase. The correlation occurs between the water quality parameter shows the relationship between the sources of pollutant. The relationship between NH_3-N and DO are associated with extensive pesticide usage for agricultural activities such as oil palm and rubber plantations, and animal husbandry at the Melaka River basin.

The correlation between pH, DO, COD, and BOD are explained based on the various sources from the anthropogenic activities such as industrial effluents, domestic wastewater, commercial activities and wastewater treatment plants at the middle stream and downstream of Melaka River. The relationship between BOD and COD was related to the source of the pollutant which possibly from sewage treatment plants and industrial effluents. The high pollution from the anthropogenic sources has given significant impact to human and aquatic life. This has proven with fish kill incident occurs along the Melaka River. High contribution of the chemical pollutant into the river also affect human health if they contact or consume with the water from the river.

4.4 Water quality index and river classification

The WQI for Melaka River was calculated based on DOE-WQI classification. Figure 4.27 shows the average WQI value for Melaka River during S1-S4. The water quality sampling was done from August 2014 until October 2014, which S1 in 21st August 2014, S2 on 4th September 2014, S3 on 19th September 2014, and S4 on 1st October 2014. The DOE WQI classified the river into three categories which are a polluted river (0-59), slightly polluted river (60-80), and clean river (81-100). During S1 and S2, Melaka River was classified as slightly polluted with the WQI value was 68 and 69, accordingly. While during the S3 and S4, Melaka River falls into polluted river categories with WQI value 59. The overall WQI result of Melaka River was categorised into Class III which suitable for water supply with extensive treatment needed, and fisheries activity by using common and tolerant species that benefits to economic values, and suitable for livestock drinking.

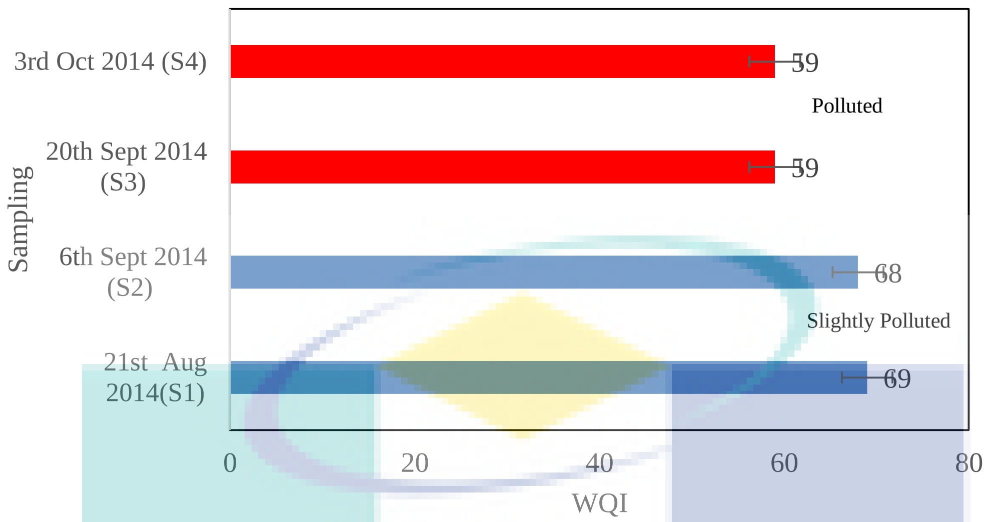


Figure 4.27 Trend of WQI during sampling 1 to 4 (S1-S4) at Melaka River within the time variation from August to October in 2014.

The time variation of WQI from S1 until S4 shows that there were no significant changes and no improvement occurs for the overall water quality result at the Melaka River. The water quality of the Melaka River was decreasing from the slightly polluted category into the polluted river category within the three months' time gaps of sampling based on the WQI result. Therefore, it was crucial to conduct the monitoring programmed along the Melaka River, to monitor the water quality status of the river and to ensure the river water quality will not over polluted. There were few factors that affected the water quality of the river such as the surrounding activities that contributes to the anthropogenic sources, time of sampling which causes the variation of environmental condition of the rivers, and the flow rate of the river water that give significant impact to the water velocities (Bhuiyan et al., 2011; Al-Mamun & Zainuddin, 2013).

Melaka River basically can be divided into three main parts which were downstream, middle stream, and upstream of the river and differentiates depends on activities occurs at the river. According to the study done by Hua (2017) and Rosli et al. (2015), the downstream area was categorised as highly polluted sites (HPS), the middle stream falls into moderately polluted sites (MPS) and upstream was describe as low polluted sites (LPS). The middle stream and upstream of the river which was near to the village, housing area, and agriculture activities there was a high contribution of pollutants from point sources and nonpoint sources into the river Hua (2017). A lot of activities occur, indicates a high level of pollution was entered the river, which may affect the health of human. The downstream of Melaka River was popular for tourism attraction with river cruise activities and sightseeing along the river, that gave a significant contribution to the high input of point sources pollution into the river (Hua & Kusin, 2015). However, for the river to be used for recreational activities involves the contact with the body, the downstream of the Melaka River need to achieve Class IIB water quality standard. Hence, in this situation, the TMDL approaches were proposed to control the water quality in the downstream area. The important information collected from WQI analysis that shows the Melaka River was categorised into Class III river, was beneficial for the TMDL approach. Based on WQI classification, Melaka River was targeted to achieve Class IIB, after the implementation of TMDL.

4.5 Water quality model analysis

This water quality model was used to study the suitable condition for improving the water quality of the Melaka River. This model consists of three main characteristics which were network, event, and water quality. The network contains a cross-section of 72 nodes along the river, with 40 km long. The network of the river was integrated with ArcGIS and AutoCAD. The event was used to build the boundary condition for the model. The upstream boundary node using the flow-time event type, while the downstream of Melaka River using stage-time as the event type. The water quality group was created for water quality analysis. There was a two-run group created which were hydraulic analysis and water quality analysis. The hydraulic analysis was carried out steady and unsteady events, while water quality analysis was used for creating scenarios for pollutant loads reduction analysis.

4.5.1 Model calibration

The model calibration was a fundamental process in developing water quality modelling to ensure the model can produce a suitable result for specific interest and purpose (Moriasi et al., 2012). The model calibration usually considers the three main elements which were (1) goals of model use, (2) data and parameter used in calibration, and (3) model calibration process (Daggupati et al., 2015). The water quality model needs to consider the important procedure such as the comparison of the model result between observed data and simulated data through the calibration process. The model calibration was a process where the model was adjusted so the model prediction was better representing the water quality model process and condition. The model was successful calibrated when it replicates observed data within an adequate level of accuracy and precision (Daggupati et al., 2015). However, the calibration process was fairly subjective to be judge, because it depends on the purpose of model development, the point of view the modeller, the available data and information, and the quality of data provided.

The water quality data collected at the upstream boundary (M20), three tributaries (P1, C1 and DT1), 14 outlets (MO1-MO14) and the downstream (M1), from August through October 2014 were used for the model calibration in the study, as shown in Figure 4.28. The model calibration was performed for two water quality parameters, which was COD and DO.

The calibration results based on water quality parameters (COD and DO) of the samples collected at 20 different stations (M1-M20) at the Melaka River was drawn in Figures 4.29 and Figure 4.30. The model was calibrated using two main water quality parameters, to fulfil the need of the study. The COD parameter was the interest parameter for TMDL approach; therefore, it was important to ensure the simulated data of COD was well-fitted with the observation data. While DO was chosen as one of the parameters for calibration analysis, based on the concept of a sequence of model: ‘which one is feeding another’ (Loucks & Beek, 2017).

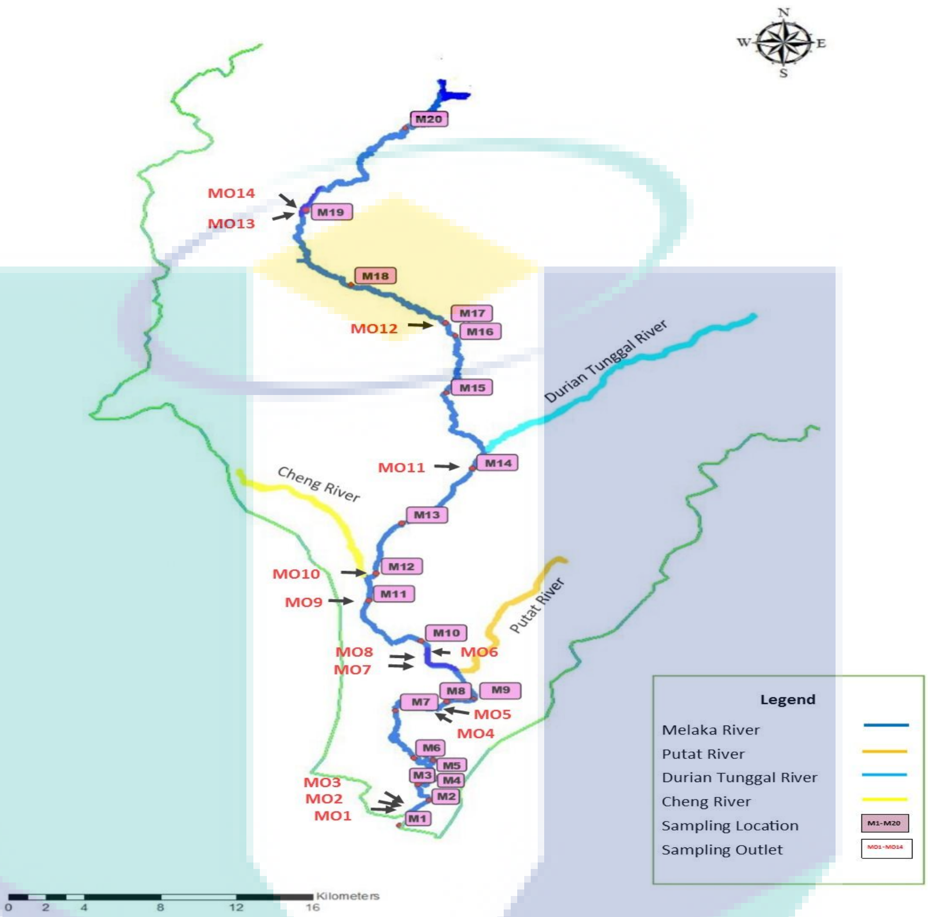


Figure 4.28 Location of point sources pollution during the calibration process along the Melaka River. The map was plotted using ArcGIS version 10.2.

To study the health of the river, the concentration of DO parameter was the most important aspect, whereas the concentration of COD was eventually have affected. Hence, these two parameters were chosen for calibration analysis. The calibration analysis was done to find the condition that best fit the water quality observation data. Based on the calibration analysis, the predicted COD parameter fits with the observation data shows the model was calibrated successfully. It shows the water quality model was suitable to use for generating the scenarios for reduction of pollutant loading analysis at Melaka River. The calibration process was important to ensure the water quality model used in accordance with the condition of the river by assessing the model parametear, as well as show the impact of pollutants into the river (Salvai & Benzdan, 2008). If the model is well calibrated by reproducing the observed water quality pattern in the river, the model can be considered as relatively reliable and accurate.

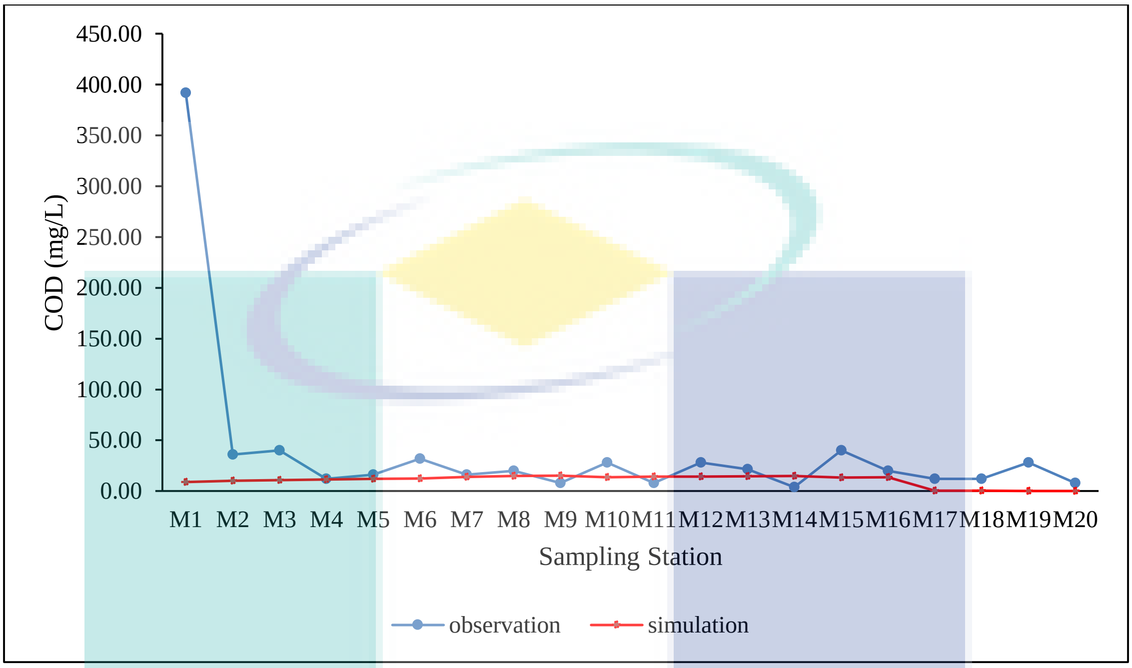


Figure 4.29 Calibration result of COD for InfoWork RS water quality modelling.

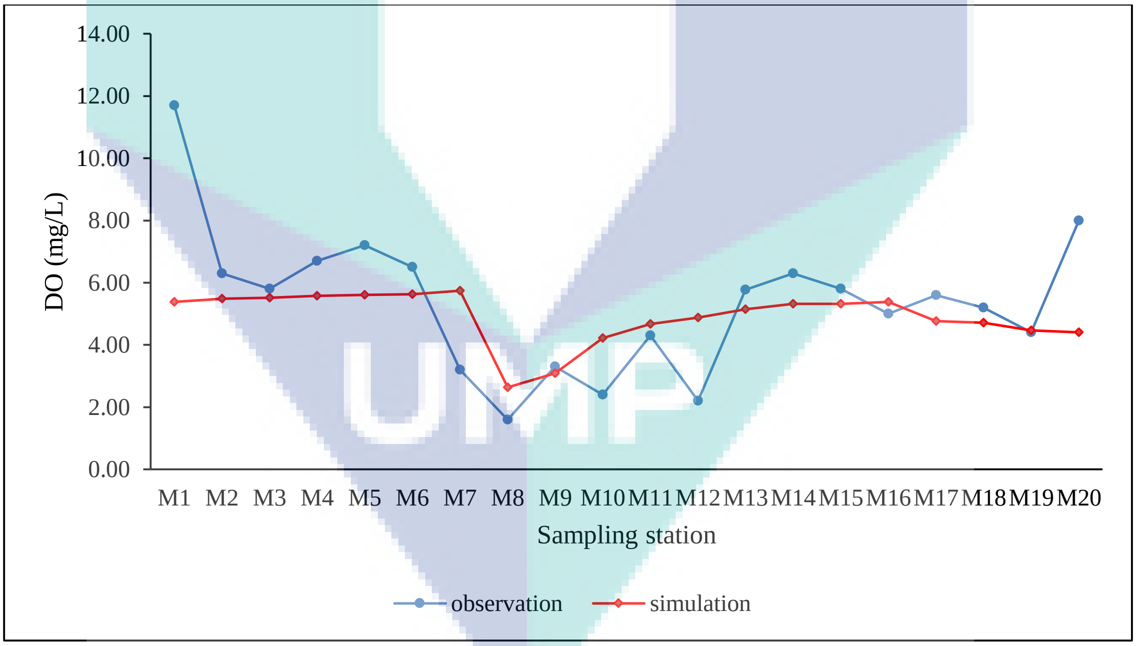


Figure 4.30 Calibration result of DO for InfoWork RS water quality modelling.

4.5.2 The scenario of COD loads analysis

The COD was selected as the target parameter for pollutant load reduction for TMDL approach based on the water quality assessment, Pearson Correlation analysis and WQI analysis. According to the water quality assessment, the COD value was higher at the downstream area, and supported with the WQI analysis shows the river was classified in Class III with the downstream area was categorised as highly polluted sites from the previous study. From the correlation analysis, the COD was found to be correlated with many parameters such as pH, DO, TP, TN and TSS. The relationship was found in the previous study done by Zou et al. (2006), Fakhraei et al. (2014), Bowen and Hieronymus (2003), and Stow et al. (2003). Therefore, the improvement of the COD parameter would contribute to the significant improvement to the other water quality parameters, as well as the water quality of the river.

After the water quality model was calibrated, the COD loads analysis was done by testing 10 scenarios of COD pollutant loads to study the changes condition of river water quality at different concentration of pollutant load. The best scenario which suitable for river water quality improvement was chosen for the TMDL implementation plan. For each scenario of pollutant loads, this model was run to predict how much the river could be improved. For each model simulation, the input file was updated with reduced pollutant loads to the river.

The summary and details of each scenario were described in Table 4.9. The scenarios were divided into three main categories which were (1) COD loads at upstream (Scenario 1 and 2); (2) COD loads at downstream (Scenario 3 and 4); (3) COD loads at tributaries (Scenario 5 and 6); and (4) COD loads at upstream or downstream and tributaries (Scenario 7-10). The flexibility occurs in scenarios created to allows the COD loads reduction analysis could be determined at all condition during the TMDL approach. Culver et al. (2002), suggested the flexibility in scenario selection for faecal coliform bacteria load reductions due to the impact of reduction to nitrate level. Therefore, the scenario created for COD loads reduction at the Melaka River was develop based on the criteria of pollutant reduction at upstream, downstream and tributaries. In Scenario 1 and Scenario 2, pollutant loads from four main point sources (MO11, MO12, MO13 and MO14) at upstream was assumed to be reduced by 30% and 50%, respectively. While in Scenario 3 and Scenario 4, pollutant loads from 10 main points sources (MO1-MO10) at downstream was assumed to reduce by 30%, and 50%, respectively. The pollutant sources at tributaries of the Melaka River (P1, C1, DT1) was reduced by 30% and 50% in Scenario 5 and Scenario 6, respectively. Lastly, in Scenario 7-10, pollutant loads from tributaries were reduced by 30% and combination with pollutant load reduction at upstream or downstream.

Table 4.9 List of scenarios for COD pollutant loads.

Criteria	Scenario	Description
Pollutant reduction of point sources at upstream	Scenario 1	30% COD loads reduction at upstream (M20, MO11, MO12, MO13, MO14)
	Scenario 2	50% COD loads reduction at upstream (M20, MO11, MO12, MO13, MO14)
Pollutant reduction of point sources at downstream	Scenario 3	30% COD loads reduction at downstream (M1, MO1-MO10)
	Scenario 4	50% COD loads reduction at downstream (M1, MO1-MO10)
Pollutant reduction of point sources at tributaries	Scenario 5	30% COD loads reduction at tributaries (P1, C1, DT1)
	Scenario 6	50% COD loads reduction at tributaries (P1, C1, DT1)
Combination of pollutant reduction of point sources at upstream/ downstream and tributaries	Scenario 7	Scenario 1 + 30% COD loads reduction at tributaries
	Scenario 8	Scenario 2 + 30% COD loads reduction at tributaries
	Scenario 9	Scenario 3 + 30% COD loads reduction at tributaries
	Scenario 10	Scenario 4 + 30% COD loads reduction at tributaries

Table 4.10 shows the summary of TMDL loads allocation for each scenario created. The pollutant loading was calculated by using equation 3.1 as shown in Chapter 3. The Scenario 1, with 30% of COD load reduction at upstream point sources need 1180.23 kg/day of COD loads reduction, with the maximum daily load of COD allowed to enter water bodies was 28339.06 kg/day. While Scenario 2 with 50% of COD load reduction at upstream point sources, need 1967.04 kg/day of COD loads reduction, with TMDL allocation was 27552.25 kg/day. The Scenario 3, with 30% of COD load reduction at downstream point sources, need 6990.92 kg/day of COD loads reduction, with the maximum daily load of COD allowed to enter water bodies was 22528.37 kg/day. The Scenario 4 with 50% of COD load reduction at downstream point sources need 11651.54

kg/day of COD loads reduction, with TMDL value was 17867.75 kg/day. Based on scenarios generated, there was an improvement in the water quality of Melaka River, however, compared with the improvement by reducing pollution sources at the upstream, the reduction of pollution loading at the downstream area show less progress. This result varies due to the consistency of flow at downstream which can be affected by the tidal effect. Furthermore, there were a lot of activities occurs in the downstream area such as tourism, development, and boating activities, that lessen the improvement of water quality of Melaka River. Therefore, the Scenario 1-4, created based on pollution reduction of point sources at upstream and downstream were not considered as the candidate for the TMDL approach.

Table 4.10 The COD pollutant loads reduction for each scenario, TMDL load allocation, and MOS allocation

Current Loading (kg/day)	**Scenario**	**WLA (kg/day)**	**TMDL (kg/day)**	**MOS (kg/day)**
29519.29	Scenario 1	1180.23	28339.06	2833.91
	Scenario 2	1967.04	27552.25	2755.22
	Scenario 3	6990.92	22528.37	2252.84
	Scenario 4	11651.54	17867.75	1786.78
	Scenario 5	684.64	28834.65	2883.47
	Scenario 6	1141.07	28378.23	2837.82
	Scenario 7	1864.87	27654.43	2765.44
	Scenario 8	2651.68	26867.61	2686.76
	Scenario 9	8131.99	21387.30	2138.73
	Scenario 10	12336.18	17183.12	1718.31

The third criteria of reduction pollution loading of point sources at tributaries which P1, C1 and DT1, which was Scenario 5, based on 30% of pollution loading reduction of COD, need 684.64 kg/day and TMDL allocation was 28834.65 kg/day. Scenario 6, with 50% of COD loads reduction at tributaries shows the reduction of 1141.07 kg/day needed, with TMDL allocated at 28378.23 kg/day. The P1 represents the Putat River, C1 represent the Cheng River, and DT1 represent the Durian Tunggal River. All these tributaries were flowing into Melaka River, and contribute a significant amount of pollution loading of COD into Melaka River. Based on scenario analysis, there was an improvement on the water quality of Melaka River. However, the result of improvement was not as expected. Due to that, there were no scenarios on the reduction of pollution loading at tributaries was a suitable candidate for the TMDL approach.

The Scenario 7-10 was created based on the combination of pollution loading reduction at upstream or downstream and tributaries. The Scenario 7 shows the combination of 30% of COD load reduction at upstream and 30% of pollution loading at tributaries, with COD loads, need to be reduced at 1864.87 kg/day, and TMDL was 27654.43 kg/day. The Scenario 8 need 2651.68 kg/day of COD loads reduction, and TMDL allocation at 26867.61 kg/day, where there were 50% of COD load reduction at upstream and 30% of pollution loading at tributaries. While Scenario 9 the combination of 30% of COD load reduction at downstream and 30% of pollution loading reduction from tributaries, with WLA, was 8131.99 kg/day, and TMDL was 21387.30 kg/day. Scenario 10 shows the condition of 50% of COD load reduction at downstream and 30% of pollution loading reduction from tributaries, with WLA was 12336.18kg/day, and TMDL was 17183.12kg/day.

The margin of safety (MOS) was important to determine the uncertainty in the TMDL (Zhang & Yu, 2004). The MOS can be expressed either implicitly or explicitly where implicit MOS was function by doing the conservative assumptions in the TMDL, while explicit MOS was reserving a part of TMDL without allocating it (Walker Jr., 2003; Zhang & Yu, 2004). In this study, the MOS has been assumed to be explicit by using the conventional method (Patil & Deng, 2011), which was allocating margin of safety at 10%. According to Zhang & Yu (2004), the explicit MOS generally equal or less than 10% of TMDL, where the MOS exceeding 10% of TMDL can be too conservative for load allocations. Studied by Minnesota Pollution control agency (2015), were also allocated 10% of MOS for TMDL load allocation of DO and Nitrate.

Figure 4.31 shows the COD load reduction needed for 10 scenarios in order to achieve the Class IIB for the Melaka River. Although Scenario 4 and 10, show the lowest TMDL allocation for COD load reduction, with the significant improvement at Melaka River, too much pollutant reduction needed can increase the cost and burden the stakeholders. Therefore, based on the most suitable, reliable and achievable pollutant reduction needed, Scenario 9 was selected as the optimum condition for COD loads reduction scenario: 30% COD-load reduction from the point sources at downstream (M1, MO1-MO10) and 30% from tributaries (P1, C1 and DT1). The implementation strategies of TMDL was created based on Scenario 9.

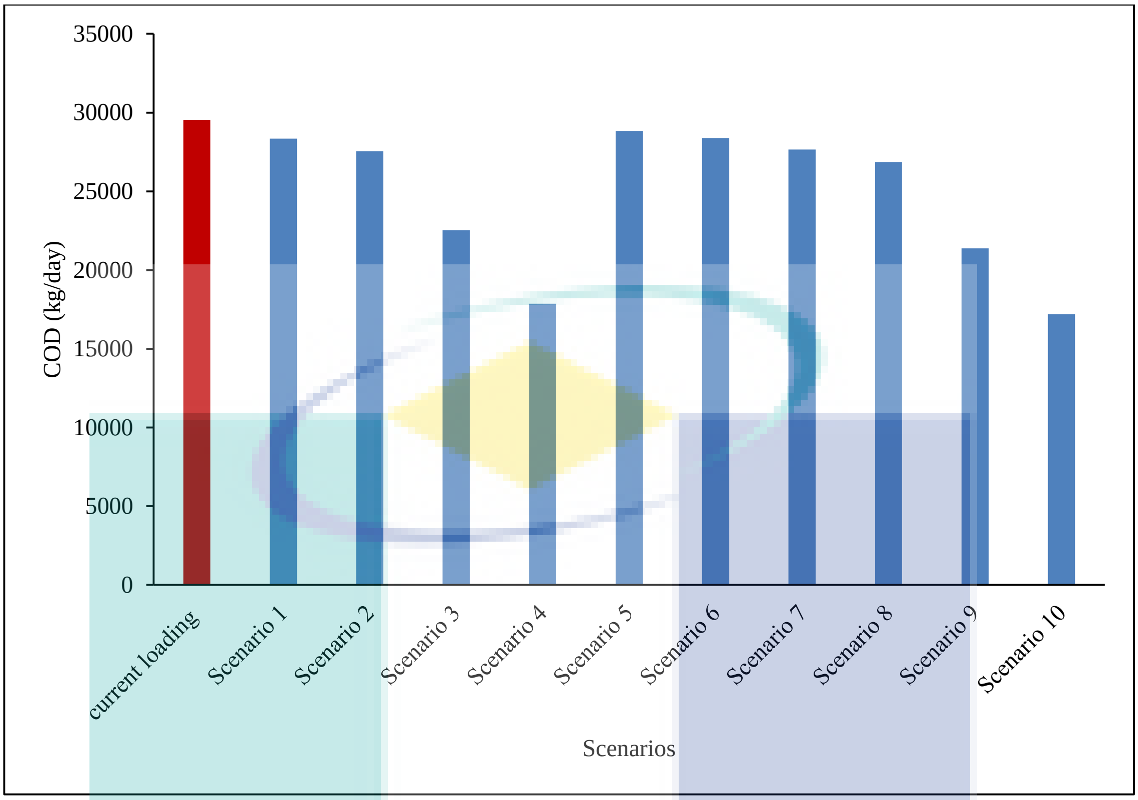


Figure 4.31 Summary of current COD loads and TMDL for each scenario analysis.

4.5.3 Choosing an appropriate scenario for TMDL implementation plan

According to the scenarios created, Scenario 9 shows the optimum condition of water quality improvement at the Melaka River. Even though Scenario 9 was a combination of reduction at point sources and tributaries, however, the amount of pollutant reduction needed was much lower than some of the other scenarios. Therefore, this Scenario 9 is selected as the candidate for the TMDL implementation plan. This selected scenario has been chosen as the target pollution reduction for TMDL approach, due to the possible pollution reduction to be done and achieving the Class II water quality standard. It is suggested the load reduction at the urban areas has the highest impact of water quality improvement (Jia & Culver 2004). Since the downstream part of the Melaka River was the urban and developing areas, it was important to control the pollution loading into the river. The study by Bowen and Hieronymus (2003), were also used scenario testing analysis, to reduce the nitrogen loading at the surface freshwater inflows. Different from this study, the nitrogen loading was reduced at the upstream area, while the downstream was left unchanged since the nitrogen loading at there were low than the upstream area. Besides, in this study, the COD was the only target parameter chosen to improve the water quality of Melaka River, supported by a study from Fakhraei et al. (2014), proved that the development of TMDL based solely on decreasing of atmospheric Sulphur (S) deposition could improve the lake acid neutralizing capacity (ANC) as much as reducing the combination of S and Nitrogen (N) deposition. Therefore, the COD was chosen as the target parameter for TMDL, based on criteria of Scenario 9.

The selected Scenario 9 as the target pollution reduction for TMDL implementation plan, need to be organized properly according to the WLA and LA sources. The centralized wastewater treatment plant can control the inclusion of pollutant load from the sewage plant for pollution loading reduction (Zhang et al. 2015). The centralized sewage plant can be treated with suitable wastewater treatment plant at the upstream of Melaka River. The study by Zhang et al., 2015, shows the pollution reduction analysis based on reducing sanitary sewage using wastewater treatment rate of sub-basin. While the nonpoint sources pollution can be controlled by implementing best management practices (BMPs) and public education (Kim et al. 2012; Love and Whitney 2008). The TMDL implementation strategies for Melaka River need to be revised and modified from time to time by using monitoring programs to monitor whether the TMDL objectives have been met or vice-versa. It was estimated that the COD loads from point sources and tributaries could be reduced as shown in Figure 4.32 when Scenario 9 was implemented for the watershed.

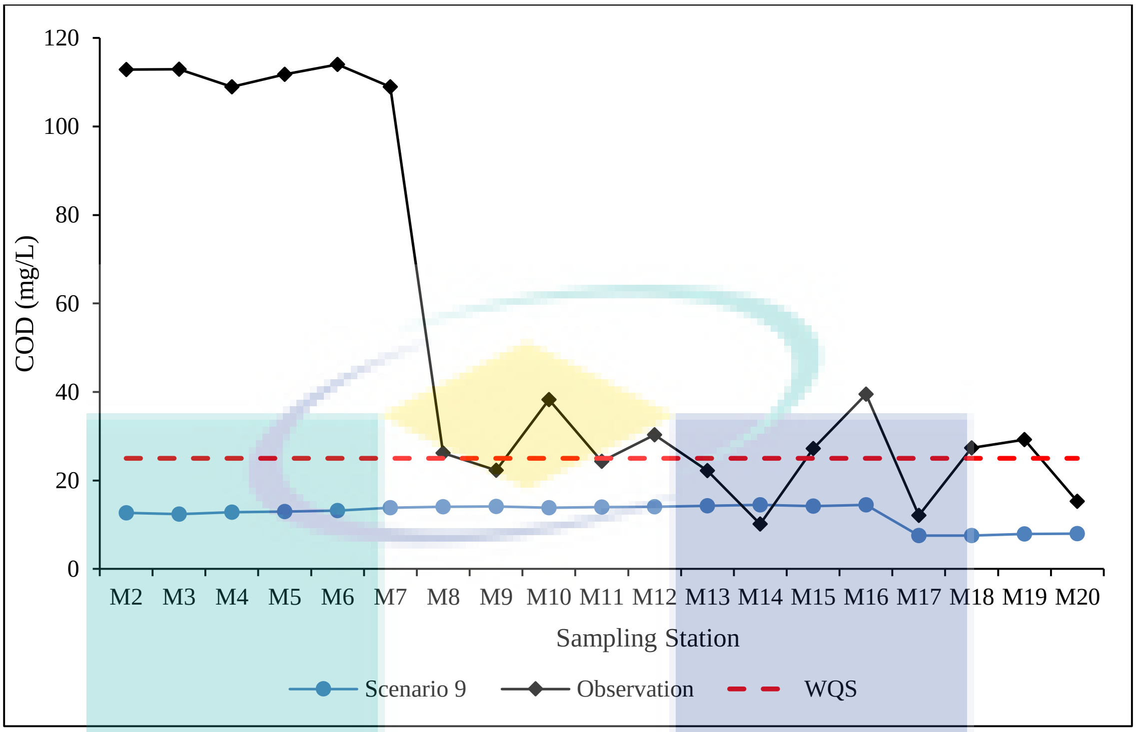


Figure 4.32 Selected Scenario 9 for TMDL development for pollutant reduction along the Melaka River.

4.6 TMDL implementation plan approach

In order to meet the loading characteristic, it has been discussed in the previous chapter, where TMDL required implementation of various policies, programs and plans focusing on improving the water quality at the Melaka River and its tributaries. These various kinds of methods requirement for water quality improvement would be either addition to, or replacement of, and improvement of current effort done at Melaka River watershed such as the cleaning and beautification of the river. The goals of the TMDL implementation plan at Melaka River was to reduce the pollutant loading into the river. Therefore, the water quality of the river was improved and within the acceptable limit to support the beneficial uses. The TMDL implementation plan for Melaka River was developed according to the "*Guidelines for Reviewing TMDLs under Existing Regulations Issued in 1992*" issued by EPA (EPA, 2018b). These guidelines provide the minimum element should appear in the TMDL plan such as identification of waterbody, pollutant concern, pollutant sources, applicable water quality standard (WQS) and target, loading capacity, LA, WLA, MOS, monitoring plan, and implementation plan (EPA, 2018a). In this study, these guidelines were used to make sure the TMDL approach was done correctly, and the modification towards the suitability for Malaysia implementation has been done. This was a significant contribution has been made to improve the watershed management system in Malaysia.

The TMDL implementation strategies for Melaka River need to be revised and modified from time to time be if monitoring programs show that the TMDL goals were not met or no significant progress toward achieving the goals. Based on the monitoring program, if the beneficial uses were supported using the TMDL program, the less restrictive load and waste load allocations can be considered. To achieve the COD reduction outlined in Scenario 9, the proper control strategies were required to apply for the wastewater discharged from the point sources and water from the tributaries. Since TMDL was derived from the combination of point sources (WLA) and nonpoint sources (LA) allocation, therefore the control strategies for reducing pollution were based on both sources. The control strategies for point sources and nonpoint sources were further discussed below.

4.6.1 Point Source Control

The main sources of pollutant load into the river was the result of point sources. To control the inclusion of pollutant load from point sources, one of the steps that can be taken was to create a treatment plant that will control the inclusion of pollutant load from the wastewater. The treatment plant can be treated with a treatment plant or facility should be built to treat the wastewater. The treatment plants planned for this purpose can consist of physical and biological processes. There were few types of the treatment plant that can be installed at Melaka River such as a membrane bioreactor (MBR), a sequencing batch reactor (SBR), an A_2O, and micro-bubble floatation can be applied.

4.6.1.1 MBR system

The MBR is the combination of a membrane process like microfiltration or ultrafiltration with a suspended growth bioreactor and is now widely applied for municipal and industrial wastewater treatment in advanced countries (Wang et al., 2012; Mitra et al., 2016; Fudala-Ksiazek et al., 2018; Mannina et al., 2018). MBR has efficiency in COD removal, and nitrification as well (Wang et al., 2012). However, this process requires large capital investment, and operation and management cost. due to an issue of membrane fouling often results in system failure (Mitra et al., 2016; Park et al., 2018).

4.6.1.2 SBR system

While, the sequential batch reactors (SBRs) was a type of activated sludge process for the treatment of wastewater and can also be called “green technology” since little or no chemicals was needed to do water treatment at low operational cost (Mojiri et al., 2018; Liu et al., 2018). Oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter (measured as BOD and COD) using a single batch reactor (Bashiri et al., 2018). The SBR can remove over 90% COD from dairy wastewater, but less efficient in treating landfill leachate and industrial wastewater compare to urban wastewater due to the low amount of BOD_5/COD ratio and high amount of heavy metals and ammonia (Mojiri et al., 2018).

4.6.1.3 A_2O system

In an A_2O system, organics, nitrogen, and phosphorus in wastewater were removed while the wastewater flows through the three different stages. Each stage was divided into equally sized, completely mixed compartments. Although this process was efficient in removing organics and nutrients, it requires a large footprint and capital investment. A study by Jena et al. (2016) found the combination of A_2O and SBR, can reduce nitrate (98%), phosphate (86%), and COD (72%) from wastewater. The combination of physical/chemical and biological treatment can maximise the removal of COD in wastewater treatment (Mojiri et al., 2018; Abedinzadeh et al., 2018). The micro-bubble floatation was a water treatment process that clarifies wastewaters (or other waters) by removing suspended matter such as oil or solids with micro air bubbles supplied by a bubble generator (Liu et at., 2010). The released air forms tiny bubbles which adhere to the suspended matter causing the suspended matter to float to the surface of the water where it may then be removed by a skimming device (Temesgen et al., 2017). This process is very effective in treating wastewater with large suspended solids. More than 90% removal efficiency can be achieved with this process. If the coagulant of a small amount is added, more than 90% P removal also can be achieved. The micro-bubble floatation has great potential, but many research needs to be carried out to optimise the application (Temesgen et al., 2017).

Considering treatment efficiency, required capital investment, and difficulty in management and operation, the combination of A_2O and SBR system was suggested as a suitable treatment plant process to be implemented for the major point sources along the Melaka River.

4.6.2 Nonpoint Source Control

For nonpoint sources or tributaries control, Best Management Practices (BMPs) one of the methods to reducing the impact of water quality issues to the watershed (Lee et al., 2010; Giri et al., 2012). The BMPs practices can be divided into agricultural BMPs and urban BMPs. The contour farming, crop rotation, nutrient management, cover crops, no-tillage, grassed waterways, constructed wetlands, grade stabilization structures, vegetated buffer strips, and blind (tile) inlets, are popular approaches used to improve water quality and reduce hydrologic impacts in agricultural areas (Liu et al., 2017). Whereas, bioretention systems, porous pavements, permeable patios, rain barrels/cisterns, green roofs, wet ponds, and dry ponds, are common practices implemented in urban areas to treat stormwater runoff quantity and quality (Liu et al., 2017). A constructed wetland along with riparian zones can be proposed as a control strategy for nonpoint sources control. Wetlands and riparian areas serve as a significant non-point source abatement system by preventing pollutants from flowing into water bodies, reducing the flow rate of runoff to allow for deposition of the pollutant or infiltration of runoff, and remediating or intercepting the pollutant through chemical or biological transformation. On the other hands, native grass and terraces methods in BMPs practices were found the most effective methods on pollutant reduction according to Giri et al. (2012) studies. The bioretention to storage treatment practices was found to manage downstream water quality and runoff volume (Johnson & Sample, 2017).

By constructing the riparian and wetlands areas can reduce the streambank and bed erosion. The benefits from this construction can improve the water quality, aquatic habitat and fish ecosystems (Smith, 2010). Besides, the other alternatives suggested for BMPs management was waste management for the animal facility, which significantly can reduce the sediment and nutrient runoff from animal facilities (Smith, 2010). By controlling the animal's activities, the improvement of water quality can be achieved. The implementation of BMPs can help in reducing the nutrient and organic compounds and improve the river conditions (Minnesota Pollution Control Agency, 2015).

4.6.3 Effective Monitoring Strategy

The evaluation of TMDL implementation effectiveness can be done by conducting a monitoring plan. The effective monitoring strategy was one of important fundamental element in evaluating the progress and impact of the TMDL implementation plan. The effective monitoring strategy helps to evaluate the improvement towards achieving the water quality standards and acknowledge the future management actions (The Cadmus Group Inc., 2011; Mirchi & Watkins, 2012). The monitoring plan should be determined before the TMDL implementation plan was done to study the effect before and after the program. The general step for developing an effective monitoring program was shown in Figure 4.33. There was an agency responsible for monitoring both mainstream and tributaries as to compliance with TMDL allocations of pollutant loading and as to progress toward supporting beneficial uses. The water quality status of the Melaka River must have monitored monthly, and the report must be submitted to the responsible parties as part of any implementation program. Based on the monitoring report, the effectiveness of the program can be determined.

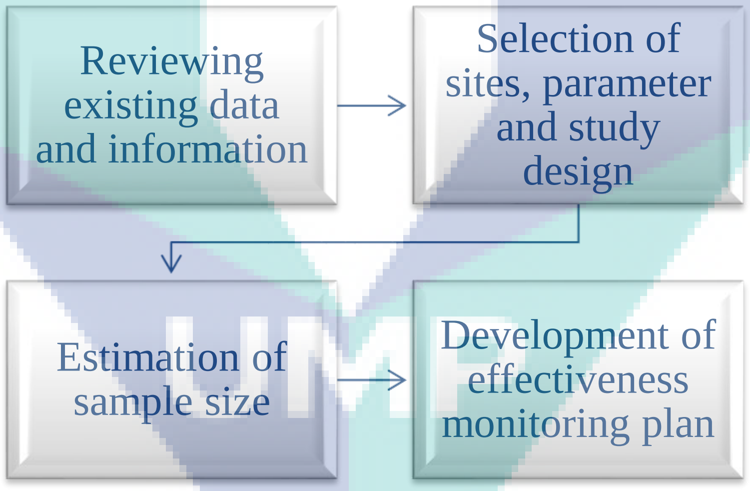


Figure 4.33 General steps are developing an effective monitoring plan.
Source: The Cadmus Group Inc. (2011)

To develop the effectiveness monitoring plan, the information and data such as TMDL implementation plans, water quality analysis, timing of TMDL implementations, existing watershed management plans, existing water quality monitoring sites and data, and watershed features and conditions need to review and analyse (The Cadmus Group Inc., 2011). It is important to study the previous data to understand the current and historic water quality condition before and after TMDL implementation. The understanding of watershed characteristic is vital for determining the successfulness of the TMDL program. The reviewing data and existing information were discussed in this chapter.

The determination of monitoring sites was done based on reviewing information and existing data to identify the location of where water quality improvement was expected to occur. The monitoring sites were determined based on the TMDL implementation plan based distributed sampling method, where more comprehensive monitoring can be done. It is suggested that there were two available monitoring stations can be used to monitor the water quality improvement. These two monitoring stations were as follow:

2322613: located at upstream Melaka River, regulated by DID

1M12: located at downstream Melaka River, regulated by DOE

Both stations were online hydrological monitoring station that collected the water quality data for 24 hours' period. By using existing water quality monitoring stations, the cost of build monitoring facilities can be reduced. Based on the selected monitoring stations, the study was designs based on a paired watershed study which was the combination of before/ after study and upstream/ downstream study. The before and after the study was done by collecting the water quality data before and after the TMDL implementation. The two monitoring stations can provide the data needed since it is already established. While the upstream and downstream is a method of control/impact study, where control (upstream) and impact (downstream) were compared. The parameter selected to be monitor consist of six main parameters need to evaluate water quality index and water quality status, which is COD, DO, BOD, SS, NH_3-N, and pH. The streamflow data were essential to measure and to calculate the pollutant and improve the water quality of the river.

There were few benefits gained from the effective monitoring plan such as providing the measurement of progress towards the TMDL implementation plan, in term of watershed restoration achievement and the efforts required for more effective progress. Besides, this plan will support the decision-making process for the allocation of funding and optimise the TMDL implementation. The monitoring plan was also assisted in providing the technical feedback that was useful for refinements of the modelling analysis.

4.6.4 Time Frame

The TMDL implementation plan usually come with the time frame to observe the progress of the program. According to EPA, the determination of TMDL for river listed in the 303d list must be done within two years, and the goal is determined in the next 8-10 years (Chen et al., 1999). The states must revisit the TMDL in the continuous planning process (Chen et al., 1999). A TMDL study at Lower Bear Malad sub-basin, show the time frame to achieve the TMDL target was within 12 years' time gap (Smith, 2010). While the TMDL plan at Melaka River has proposed five years' time frame to observe the progress of the implementation plan. This time gap also has been proposed by Tennessee Department of Environment and Conservation (2017), the effective time frame to monitor TMDL progress for E. coli was suggested within five years' time gap with the adequate sampling frequency. Table 4.11 shows the suggested time frame for TMDL implementation plan at Melaka River. The action plan duration was divided into three categories which are a short-term plan, mid-term plan and long-term plan, and can be implemented in any rivers listed as a polluted river. The program needs to be revised every 5 years, and the modification and improvement can be done based on the water quality status of the river. The time gap of revising the TMDL program at Melaka River was decided to be within the five years gaps, to ensure the TMDL approach has been well implemented.

Table 4.11 Proposed action plan of TMDL for the Melaka River.

Short-term plan (1-2 years)
1. Conduct the data collection: Identify sources of pollution Collection of river water quality data, hydraulic and hydrology data from relevant agencies Identify activities conducted in river basins Identify the committed development involved Ensuring the development plan is in line with TMDL's plan Identify river water quality status
2. Coordinate the data collection from relevant agencies
3. Identify the list of polluted river basins
4. Prepare the TMDL implementation plan for the polluted river
5. Identify state-level bodies that were most appropriate to monitor the implementation of the TMDL plan
Mid-term plan (3-5 years)
1. Identify policies and regulations suitable for the implementation of TMDL
2. Establishment of a task force to resolve inter-agency issues
3. Implementation and enforcement of TMDL plans at the state level
4. Monitoring the TMDL implementation
Long-term plan (5 years and above)
1. Ensuring the implementation and enforcement of the TMDL plan is carried out comprehensively
2. Review and revise the effectiveness of the TMDL plan
3. Review of deeds or legislation, enforcement and maintenance at state and federal levels
4. The awareness program on the importance of TMDL is done comprehensively and continuous

4.6.5 Modification of government policies

To achieve the target water quality based on the TMDL program, it might require changes in current agency operations. These changes required several types of legislative action and local action to ensure the program are well defined and implemented. Some modification and improvement might need financial assistance and cooperation from many responsible parties. Nature itself might be the biggest challenge in developing the programs. There were available acts and enactment that already available and used to control the pollution at the river as shown in Table 4.12. However, weak enforcement makes no changes occurs. Despite the above, there was no reason not to see substantial progress within 10 years of the discharge of the implementation plan. Development of a proper monitoring plan should allow statistical evaluation of that progress.

Table 4.12 Types of Acts/ Enactment

Types of Acts/ Enactment	Responsible Party
Enakmen Sumber Air (Negeri Melaka) 2014	Water Regulatory Body (BKSA)
Akta Industri Perkhidmatan Air 2006 (Akta 655) (Eg:Kawalan Tangki Septik)	National Water Services Commission (SPAN)
Akta Kualiti Alam Sekeliling 1974 (e.g: Pelepasan Effluent)	Department of Environment (DOE)
Syarat-Syarat Perlesenan	Local authority (PBT)
River Monitoring System River Monitoring System	Lembaga Urus Air Selangor (LUAS)

4.6.6 Responsible Parties

The implementation of a plan to improve water quality in the Melaka River watershed requires the cooperation of many parties. Each party can play their roles in contributing to the TMDL program according to their available sources. These may include, but not be limited to, as follow:

i. Department of Environment (DOE)

ii. Federal Department of Town and Country Planning Peninsular Malaysia

iii. Department of Fisheries

iv. Department of Drainage and Irrigation Malaysia (DID)

v. Ministry of Works (JKR)

vi. National Hydraulic Research Institute Malaysia (NAHRIM)

vii. Fisheries Research Institute (FRI)

viii. National Water Services Commission (SPAN)

ix. District and Land Office

x. Water Regulatory Body Melaka (BKSA)

xi. Ministry of Energy, Green Technology, and Water (KeTTHA)

4.7 Challenges in developing TMDL in Malaysia

There were few challenges that need to be considered during the development of TMDL in Malaysia, before, during and after the development process of TMDL. On 2nd December 2015, a workshop on presenting the finding of TMDL research at Melaka River was held, involving 26 participants from all related government agencies. This workshop aimed to present the TMDL results of Melaka River while providing information to stakeholders regarding the implementation of TMDL. At the end of this workshop, survey forms were distributed to obtain feedback on the implementation of TMDL from all stakeholders.

According to the survey conducted, 69% of the stakeholders already possessed the knowledge and information about TMDL. However, only 2% of them have a deeper understanding of the TMDL process, while 15% of them know only the basic information on TMDL. Unfortunately, 69% of them were uncertain about TMDL. Besides, 47% of stakeholders agree that the existing water quality control of rivers in Malaysia cannot improve the quality of the river, whereas 38% of them do not agree with that statement. While others have expressed ambiguity regarding these issues. The impact of TMDL implementation on the state, governing body and economy were sought, whereby 39% of the stakeholders believe that TMDL implementation will significantly impact the state, 54% of them believe that TMDL will significantly impact both, the governing body and the economy. Stakeholders that push for change also believe that the laws, enforcement, funding and state government roles will form the biggest challenges in implementing TMDL in Malaysia.

Based on the workshop, the stakeholders believe that strong cooperation between government agencies and authorities can improve and maintain the water quality of the river. Besides, it is also suggested that cooperation with the private sector should be enhanced and the enforcement needs to be improved. By controlling the number of pollutants from nonpoint sources (NPS) and point sources (PS) such as premises, from entering the water body, greater improvement of river water quality will occur (Zhang & Jorgensen, 2005). The challenges of the TMDL approach were further discussed below.

4.7.1 Fundamental Challenge

There were many challenges that need to be faced in implementing TMDL to achieve the desired water quality. Malaysia is a developing country, poses basic challenges that need to be considered during the development process. Among the fundamental challenges which must be dealt with to ensure that development can be carried out successfully, include the need for additional funding in the research process. This funding would be particularly helpful to encounter problems related to non-point source pollution. A lack of funding sources delays and affects the whole TMDL research process.

The development process requires sufficient data, which was important to ensure the results produced was reliable and accurate. However, the presence of a huge gap in the data supplied, previous research and monitoring will affect the results of the conducted research. This study also requires the close cooperation of each multi-jurisdictional body or agency to identify water quality problems that arise and to produce solutions that can benefit all parties. Strong collaboration is important to ensure smoothness in implementing TMDL in Malaysia. Accurate and comprehensive explanations were needed to ensure that all parties understand the purpose of ongoing TMDL, and the benefits provided.

4.7.2 Involvement of stakeholders

The involvement of stakeholders may pose challenges on the development activity based on time, their commitment and their priorities (Cabrera-stagno, 2007; Gaddis et al., 2010). Their involvement may delay the TMDL approach, during the process of waiting for the input and contributions. Thus, involving stakeholders may significantly delay the water quality project, and some of the stakeholders may forfeit their participation in this project due to the lengthy timeline. Next, the varying interests of stakeholder priority can be the biggest challenge of their involvement (Johnson, 2008). It is hard to ensure that all stakeholders have the same priorities in improving the water quality of the river. Some of the stakeholders may focus on the development of the river, to reduce the impact of floods or to solely reap the economic benefits the river can provide to the state. Thus, these differences create conflict between them.

Furthermore, TMDL itself will only concern with a single parameter during the development to reduce the pollutant. However, nature is complex and constantly changing. Therefore, only focussing on reducing the targeted parameter can be burdensome for some stakeholders. They need to ensure that reducing the targeted pollutant will not affect the financial interests of their department. Gaining stakeholder trust to ensure that their involvement provides funding to the TMDL program may well be the hardest part of the entire process. The development of a water quality model for TMDL comes with a level of uncertainty must be based on the effectiveness of the model and predictions of the solution to solve the water quality problem. However, the involvement of stakeholders in the development process allows the exchanging of information and resources (Gaddis et al., 2007).

4.8 Summary

This study has successfully established the proposed TMDL implementation plan for Melaka River based on water quality assessment, Pearson correlation analysis, WQI analysis, and water quality modelling analysis. This chapter has drawn several key conclusions as follows:

During water quality assessment, the target water quality parameter and water quality standard for TMDL approaches has been recognised. The water quality parameter COD has been chosen as a target for TMDL implementation plan, to achieved Class IIB. Besides, the water quality assessment the others parameter such as DO, NH_3-N, and BOD show the impairment of water quality of Melaka River.

This study has established a Pearson correlation analysis, to prove the correlation exists among the parameter. The findings show there was correlation exist between COD and another parameter such as DO, TP, TN, and TSS. Based on this exist correlation of COD and other parameters, this study strongly believes that significant improvement will occur for other parameters, parallel with COD reduction during the TMDL implementation.

Furthermore, it is found that the WQI analysis according to four times sampling has classified Melaka River at Class III. In up to date data information from DOE, from 2011-2016 the Melaka River is still classified as Class III. Therefore, from the WQI analysis, the TMDL implementation at Melaka River was targeted to achieved Class IIB, which suitable for recreational use with body contact.

The more surprising finding was the contribution of InfoWorks River Simulation water quality model finding, which 10 scenarios of COD loads reduction analysis were developed. Based on the water quality modelling analysis, the pollutant load reduction needed to be achieved by TMDL implementation was determined. The Scenario 9 was selected as the most suitable scenario to implement TMDL, with 30% of pollution reduction at downstream (M1, MO1-MO10) and 30% of pollution reduction at tributaries (P1, C1, DT1) were needed. The MOS was assigned explicitly with 10% from total load allocations.

The most critical part of this study was discussed in this chapter, TMDL implementation strategies. The point sources and nonpoint sources control was suggested for COD loads reduction to be achieved. The combination of A_2O and SBR treatment plant was suggested to be implementing to control the intrusion from point sources pollution. While BMPs was suggested to reduce the impact on water quality pollution from nonpoint sources.

The TMDL implementation plan for Melaka River in this study has a significant contribution by suggestion the effective monitoring strategy and time frame to evaluate the effectiveness and successfulness of the TMDL approach. In the effective monitoring two available monitoring station was suggested to monitor the water quality improvement. While five years' time frame was suggested to monitor the TMDL progress and successfulness.

There might be changes needed in government policies, the types of available act and enactment was listed for further improvement and changes. This study also provides suitable agencies to be responsible for TMDL implementation at Melaka River.

Finally, the challenges need to be faced during the TMDL approach in Melaka River, Malaysia especially was discussed in this study. This was important to ensure all parties involved are prepared to face the challenges in TMDL approach.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion and contribution of the study

In the present work, the TMDL implementation plan approach was suggested to ensure the water quality of the river were restored and maintained, and several important finding with significant contribution has been found in this study. As a general conclusion, the finding from this work has contributed to a few suggestions for the improvement of the TMDL implementation plan for the near future.

This study was aimed to evaluate the spatial and temporal variation of surface water quality in the Melaka River. From the evaluation of water quality analysis, the most polluted parameter has been recognised, which is COD. The statistical analysis by using SPSS model for Pearson Correlation analysis found out the significant correlation between the concentration of pollutant loads, which provides a strong judgement with the origin of pollution sources. All this data, including the in-situ data and laboratories analysis data, was one of contribution to the body of knowledge during this study. On the other hands, this study was also able to collect the significant secondary of hydrology and hydraulic data from government agencies such as DID and DOE for the water quality model analysis. It provides a better understanding of the evaluation of the water quality condition at the Melaka River.

This study also aimed to calculate the water quality index of the Melaka River by using the formula established by the Department of Environmental (DOE). Based on the present work, the Melaka River water quality status was classified under Class III according to the WQI classification. In the TMDL implementation plan approach, it is important to recognise the WQI of the Melaka River before and after the TMDL implementation plan. This is important to ensure the TMDL approach has achieved the target. The Class III indicates that the river slightly polluted and only suitable for water supply with extensive water treatment, and fisheries activities for common and tolerant species. COD was the selected water quality parameter for TMDL implementation plan, due to the higher concentration of COD especially at the downstream part were recorded at Melaka River. According to the analysis, the reduction of COD has significantly improved the water quality of the river. Therefore, the reduction of COD pollutant loads into the Melaka River has been suggested using suitable TMDL implementation plan to implement in Malaysia. The Melaka River was targeted to achieved Class IIB water quality after the TMDL implementation based on the WQI analysis method. It is crucial to monitor the results before and after the implementation, to ensure the result was significant and reliable. This effort, in turn, shall be supported with the water quality data from DOE, that indicated the Melaka River still in Class III from the years of 2011-2016.

Another important aim in this study was to perform a water quality model of the Melaka River by using InfoWorks RS version 10.5 for COD loads analysis. From the modelling analysis, there were 10 scenarios been simulated to calculate the allowable load of pollutant, and the Scenario 9 has been chosen as the optimum scenario to achieve the target water quality standard which Class IIB. In order to achieve Class IIB, the concentration of COD must be less than 20 mg/L. The specific TMDL plan was created to achieve Scenario 9 condition. The water quality model analysis was important to determine the reduction of pollutant loads needed to be done.

This study was also aimed to create a TMDL implementation plan approach for suitable watershed strategies in the Melaka River. In order to reduce the pollutant loads, the TMDL approach has suggested two main methods, which are point sources control and nonpoint sources control. The point sources control was suggested by using the wastewater treatment plant, while nonpoint sources control was by using Best Management Practices (BMPs) to reduce the COD loads. Besides, this study might produce knowledge and information that can be benefited during the TMDL approach, since it also suggested the effective monitoring strategy to monitor the effectiveness of the program, the timeframe for the implementation plan, and the modification of government policies, and responsible parties.

This study has been highlighting TMDL as the main approach to be implemented in Malaysia, whereas the implementation program in the United States and Asia countries such as South Korea and China have been used as the guidelines. Based on studies from previous work, several improvements can be done for watershed management in Malaysia using the TMDL program such as recognised and creates the list of impaired water for river and lakes in Malaysia. The list of impaired water of river and lakes in the United States was created to ensure all the impaired waterbody will develop and implement the TMDL programmed.

Despite of all challenges during the process of TMDL implementation plan, a study done by Cropper and Isaac (2011) shows the TMDL program can benefit in few ways such as improved water quality to homeowner who lives near the river, recreational benefits to the fishers, swimmers and boaters and benefits to the public values who cares about the river. These benefits were gained from the implementation of the TMDL program.

5.2 Limitation of study

However, there were several challenges discovered during this study such as there is a need for specific actions for the implementation of the TMDL approach in Malaysia. The specific act or enactment is required to assist during the process of planning, implementing and monitoring the effectiveness of TMDL in Malaysia. Besides, the poor river data management system has been complicating the implementation of the TMDL program in Malaysia. The data of the river were not well coordinated, organised and maintained that causes delays in the TMDL implementation. For the TMDL approach, huge data were required, and the absence of some data might affect the process. Another challenge in order to develop TMDL was ineffective and non-transparent law enforcement. This leads to widespread and uncontrolled pollutants loading into the river. The biggest challenge to save the river is the lack of awareness about the importance of preserving and conserving rivers among the public, and the local community has led to the increasing contamination of the problem to the river.

When regulating a new implementation or set of rules in Malaysia, exists a variety of concerns that would arise among politicians, regulatory agency, and the administration. For example, in the United States, the TMDL development process considers the role that would be acquired by the federal government in water quality management during the revision of TMDL regulation, and consequently whether it would challenge the relationship between the EPA and the state government. These concerns should be accounted for in the TMDL development in Malaysia. The development of TMDL will add to the workload of the departments concerned, as their staff would still need to carry out the programs that already exist for water quality management. In addition, there is also a concern about whether there were enough resources able to carry out the TMDL requirements.

5.3 Future Works

From the experienced conducting TMDL studies in Malaysia, there are few recommendations to achieve better management of river in the future in Malaysia as suggested:

i. Since the rivers in Malaysia were not assigned for the specific designated uses. The designated used for each river can determine the specific water quality condition of the river. Therefore, the determination of the reduction of pollutants loads become easier and effective. Besides, the list for impaired water body in Malaysia based on their priority can be constructed such as the 303d list created by EPA for the impaired water body. By having this list, the government can ensure that the state plays their active roles in the preservation and conservation of river quality and health.

ii. Furthermore, the coordinate data of the river obtained from government agencies need to be more systematic and manageable. The data must be updated from time to time. This can help in reducing the time for data collection during the TMDL process.

iii. Besides, the training on water quality modelling as the planning tools for the TMDL approach needs to enhance, to ensure the developed modelling were reliable and accurate.

iv. Since there are no specific act or enactment for the TMDL program, the establishment of specific actions can make sure that the TMDL program can be run in a systematic and accordance with the established procedures.

v. In addition, to improve the understanding of TMDL programs, training programs need to be conducted. The training program can involve the theory and technical aspect of the implementation of TMDL at every level of jurisdiction. The comprehensive approach is needed to raise the awareness of the public and community about the importance of preserving and conserving our river.

vi. Additionally, talks program about TMDL programs can be done through social media such as Facebook, Instagram, and Twitter, and special events can improve the understanding and information TMDL implementation plan approach.

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APPENDIX A

Table A1 Sampling stations at Durian Tunggal River

Location	Latitude (N)	Longitude (E)	Explanation
DT1	2°18'03.66"	102°15'49.92"	At the downstream of river
DT2	2°18'28.18"	102°16'19.48"	At the Jalan Padang Keladi, near to the pond
DT3	2°18'43.35"	102°16'47.08"	At the Orchard area, near to the cattle and sheep farms, village area
DT4	2°18'50.16"	102°16'56.64"	At the Durian Tunggal bridge, Durian Tunggal town area
DT5	2°19'24.18"	102°17'27.60"	Near to the Batu Resam water level station
DT6	2°19'42.84"	102°17'52.86"	Near to the Jama Enterprise fish ponds, upstream area of Durian Tunggal River

Table A2 Sampling stations at Cheng River

Location	Latitude (N)	Longitude (E)	Explanation
C1	2°16'45.24"	102°13'49.02"	Near to the Ifineon industrial area, at the downstream of river
C2	2°17'26.63"	102°14'08.86"	Near to the estate and Hang Jebat Stadium
C3	2°18'06.00"	102°13'52.26"	At the banana and palm oil plantation area, there are discharge from canal
C4	2°18'50.54"	102°13'16.34"	Near to the Sasha Enterprise chicken processing farm and rural area
C5	2°19'06.13"	102°13'07.22"	At the rural area
C6	2°19'26.01"	102°12'46.05"	At the rural area

Table A3 Sampling stations at Putat River.

Location	Latitude (N)	Longitude (E)	Explanation
P1	2°14'10.41"	102°15'41.39"	Near to the IWK treatment plant, at Jalan Akasia 4, at the downstream of river
P2	2°14'25.97"	102°15'47.60"	At Lorong Haji Jalil, near to the bridge and housing area
P3	2°14'36.53"	102°15'58.63"	At Taman Kerjasama estate, there was discharge from outlet
P4	2°15'20.40"	102°16'12.78"	At Taman Bukit Beruang Estate
P5	2°16'06.36"	102°16'47.16"	Near to the UTEM residential area
P6	2°15'54.84"	102°17'02.94"	Near to the factories, school and livestock area

Table A4 In situ data for Durian Tunggal River

Location	Date	pH	DO (mg/L)	Temp (°C)	Conductivity (uS/cm)	Salinity (ppt)
DT 1	20/8/2014	6.99	4.90	27.1	47.89	0.0572
	5/9/2014	4.50	7.80	26.2	44.19	0.0530
	17/9/2014	6.92	10.3	26.0	111.7	0.0987
	30/9/2014	7.02	3.69	29.6	86.91	0.9829
DT 2	20/8/2014	7.05	5.60	28.2	43.50	0.0530
	5/9/2014	3.78	6.11	26.0	44.37	0.0533
	17/9/2014	6.93	9.40	26.4	106.50	0.0947
	30/9/2014	7.02	3.98	29.4	84.70	0.0972
DT 3	20/8/2014	7.03	6.80	26.8	43.18	0.0521
	5/9/2014	8.8	5.86	26.0	42.67	0.0517
	17/9/2014	6.93	9.30	27.0	119.30	0.1062
	30/9/2014	7.02	3.50	29.1	91.19	0.1039
DT 4	20/8/2014	6.78	5.86	26.0	42.67	0.0517
	4/9/2014	8.44	6.80	26.8	43.18	0.0521
	19/9/2014	7.13	6.00	34.5	124.4	0.1031
	1/10/2014	7.03	2.85	28.5	101.8	0.1062
DT 5	20/8/2014	6.86	6.11	26.0	44.37	0.0533
	4/9/2014	7.05	5.60	28.2	43.50	0.0530
	17/9/2014	6.94	5.00	29.2	132.50	0.1172
	1/10/2014	6.98	2.77	27.0	101.50	0.1169
DT 6	20/8/2014	6.93	7.80	26.2	44.19	0.0531
	4/9/2014	6.99	4.90	27.1	47.89	0.0572
	17/9/2014	6.95	4.40	30.1	177.7	0.1659
	1/10/2014	6.97	2.85	28.1	116.3	0.1150

Table A5 Laboratory analysis data for Durian Tunggal River

Location	Date	PO_4^{3-} (mg/L)	TP (mg/L)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	TN (mg/L)	NH_3-N (mg/L)
DT 1	20/8/2014	0.6336	0.6441	37.34	12.20	548.00	0.7514	0.0524
	5/9/2014	0.1200	0.1610	7.91	23.80	6.33	0.1794	0.1323
	17/9/2014	0.1950	0.3704	4.00	7.50	9.67	0.3317	0.1370
	30/9/2014	0.1119	0.3865	4.00	9.30	35.33	0.4881	0.2424
DT 2	20/8/2014	0.9002	0.9179	29.05	11.20	529.33	0.3111	0.2971
	5/9/2014	0.1100	0.1449	31.62	16.50	5.67	0.2165	0.1373
	17/9/2014	0.0973	1.3527	16.00	7.30	8.33	0.3481	0.3181
	30/9/2014	0.0900	0.6280	4.00	7.30	29.33	0.4346	0.1897
DT 3	20/8/2014	0.8626	0.9179	41.49	11.10	577.33	0.6074	0.3969
	5/9/2014	0.2800	0.2899	16.13	12.30	577.33	0.3523	0.0924
	17/9/2014	0.0817	0.2738	8.00	9.00	11.33	0.2576	0.2041
	30/9/2014	0.0984	0.7085	12.00	5.90	21.33	0.3893	0.2778
DT 4	20/8/2014	0.6149	0.7890	49.79	12.00	593.00	0.6897	0.2971
	4/9/2014	0.2600	0.4026	27.67	1.70	14.33	0.2905	0.1423
	19/9/2014	0.0900	0.2093	24.00	5.70	23.00	0.3975	0.2650
	1/10/2014	0.1586	0.4187	4.00	30.20	628.67	0.5498	0.2123
DT 5	20/8/2014	0.9977	1.2238	37.34	11.30	599.00	0.4675	0.3570
	4/9/2014	0.3400	0.5797	7.91	3.00	599.00	0.3440	0.1428
	17/9/2014	0.1524	0.3704	4.00	10.50	15.00	0.2988	0.2284
	1/10/2014	0.2085	1.5298	12.00	18.80	38.33	1.0313	0.3029
DT 6	20/8/2014	0.5811	0.7729	29.05	6.80	589.00	0.6527	0.4518
	4/9/2014	0.1900	0.2254	72.58	3.10	930.00	2.9778	0.3020
	17/9/2014	1.2004	10.5636	56.00	17.50	599.00	0.4757	0.2580
	1/10/2014	0.1254	0.6280	36.00	16.20	19.00	0.5004	0.4716

Table A6 In situ data for Cheng River

Location	Date	pH	DO (mg/L)	Temp (°C)	Conductivity (uS/cm)	Salinity (ppt)
C1	19/8/2014	6.27	5.30	32.4	498.20	0.576
	3/9/2014	6.64	4.80	32.9	865.90	1.030
	16/9/2014	6.88	4.60	27.7	1104.00	1.032
	30/9/2014	7.01	4.01	29.9	394.20	0.457
C2	20/8/2014	6.81	5.50	26.7	317.40	0.370
	3/9/2014	7.13	3.30	32.0	1134.00	1.355
	16/9/2014	6.90	2.30	29.6	1398.00	1.309
	30/9/2014	6.97	3.44	31.2	736.90	0.867
C3	20/8/2014	6.76	5.50	26.9	518.00	0.600
	3/9/2014	7.54	2.00	31.3	1427.00	1.757
	16/9/2014	6.93	1.80	30.5	2181.00	2.105
	30/9/2014	7.04	2.79	33.4	1530.00	1.884
C4	20/8/2014	6.85	5.10	27.1	701.2.00	0.810
	3/9/2014	7.52	2.20	31.2	2810.00	3.511
	16/9/2014	6.92	1.80	31.0	2409.00	2.307
	30/9/2014	7.02	2.36	32.7	1697.00	2.057
C5	20/8/2014	7.01	3.60	27.6	898.50	1.063
	3/9/2014	7.60	2.80	29.8	3055.00	4.020
	16/9/2014	6.85	1.60	31.5	2476.00	2.399
	30/9/2014	7.01	1.93	31.9	1774.00	2.224
C6	20/8/2014	4.30	6.89	27.8	1019.00	1.025
	3/9/2014	7.53	2.20	29.6	3365.00	4.179
	16/9/2014	6.94	1.50	31.7	2467.00	2.380
	30/9/2014	7.03	1.89	31.5	1653.00	2.039

Table A7 Laboratory analysis data for Cheng River

Location	Date	PO_4^{3-} (mg/L)	TP (mg/L)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	TN (mg/L)	NH^3-N (mg/L)
C1	19/8/2014	0.5360	0.6119	16.60	10.20	46.00	0.2453	0.2421
	3/9/2014	0.9500	1.0789	72.58	8.50	49.33	0.7432	0.4868
	16/9/2014	0.8545	2.7053	32.00	4.00	46.67	0.7021	0.2189
	30/9/2014	0.1565	0.9179	44.00	2.80	43.00	0.5786	0.2720
C2	20/8/2014	0.5848	0.9501	8.30	10.50	110.33	0.1712	0.0974
	3/9/2014	1.7300	2.3027	68.55	5.80	58.00	0.2741	0.2222
	16/9/2014	0.9428	2.6087	52.00	20.90	37.00	0.5745	0.1276
	30/9/2014	0.5356	1.3366	128.00	8.80	66.33	0.5745	0.2309
C3	20/8/2014	0.9077	0.9179	8.30	16.90	63.00	0.1671	0.1323
	3/9/2014	1.8800	1.9324	44.35	8.80	12.33	0.1300	0.6316
	16/9/2014	1.0342	3.3655	36.00	0.90	17.33	0.4428	0.4881
	30/9/2014	0.7517	1.3205	60.00	1.60	27.00	0.2494	0.1296
C4	20/8/2014	1.3994	1.4171	41.49	15.30	52.67	0.2082	0.1223
	3/9/2014	1.9200	1.9646	76.61	0.50	14.67	0.1794	0.1223
	16/9/2014	1.0892	3.8325	44.00	4.30	19.33	0.1918	0.1251
	30/9/2014	0.7745	1.5942	164.00	9.70	14.33	0.3646	0.3782
C5	20/8/2014	1.0691	1.1755	41.49	18.20	38.00	0.2206	0.1273
	3/9/2014	1.3600	1.8196	36.29	13.50	12.00	0.1383	0.1173
	16/9/2014	1.0788	3.9291	52.00	12.70	18.00	0.1177	0.1284
	30/9/2014	0.7641	1.6103	64.00	12.10	10.33	0.1959	0.1620
C6	20/8/2014	0.5360	0.6119	16.60	10.20	46.00	0.2453	0.2421
	3/9/2014	1.2500	1.5298	52.42	6.00	0.67	0.1424	0.1073
	16/9/2014	1.0498	4.4122	20.00	18.00	16.00	0.1259	0.1321
	30/9/2014	0.7444	1.4493	60.00	13.30	12.67	0.1753	0.1440

Table A10 In situ data for Putat River

Location	Date	pH	DO (mg/L)	Temp (°C)	Conductivity (uS/cm)	Salinity (ppt)
P1	19/8/2014	6.78	3.30	34.3	4447.9	0.5081
	6/9/2014	4.01	5.50	27.0	416.3	0.4734
	16/9/2014	6.94	3.00	31.4	597.0	0.5374
	30/9/2014	6.99	4.22	26.8	157.2	0.1631
P2	19/8/2014	6.87	3.20	34.1	447.8	0.5205
	6/9/2014	3.95	5.50	28.9	459.9	0.5423
	16/9/2014	6.30	2.30	31.3	572.9	0.5129
	30/9/2014	7.03	3.36	25.4	131.1	0.1480
P3	19/8/2014	7.02	2.40	34.3	501.3	0.5735
	6/9/2014	3.75	4.00	32.5	475.3	0.5486
	16/9/2014	6.89	2.40	31.6	670.9	0.6026
	30/9/2014	6.97	3.25	29.1	320.3	0.3643
P4	19/8/2014	7.56	2.40	34.4	504.4	0.5811
	3/9/2014	7.20	3.40	30.7	407.3	0.4724
	16/9/2014	6.91	1.60	33.0	557.0	0.5013
	30/9/2014	6.94	3.74	26.2	103.8	0.1171
P5	19/8/2014	8.51	4.80	32.4	664.9	0.7751
	3/9/2014	6.21	5.60	29.7	562.1	0.6458
	16/9/2014	6.88	3.90	31.5	753.6	0.6836
	30/9/2014	6.97	3.80	29.1	259.4	0.2979
P6	19/8/2014	8.15	3.90	33.0	26.89	0.0440
	3/9/2014	7.68	5.30	29.6	1129.0	1.3050
	16/9/2014	6.97	2.40	31.0	1697.0	1.0680
	30/9/2014	7.03	3.53	29.4	817.3	0.9683

Table A11 Laboratory analysis data for Putat River

Location	Date	PO_4^{3-} (mg/L)	TP (mg/L)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	TN (mg/L)	NH_3-N (mg/L)
P1	19/8/2014	0.2470	0.2576	16.60	10.20	24.33	0.1753	0.1173
	6/9/2014	0.4800	0.6119	16.13	12.20	7.00	0.3691	0.2921
	16/9/2014	0.1586	0.6441	36.00	16.30	19.33	0.6856	0.1733
	30/9/2014	0.3248	3.4944	44.00	11.90	141.33	1.4593	0.1218
P2	19/8/2014	0.2545	0.5636	12.45	11.20	21.00	0.2123	0.1323
	6/9/2014	0.0100	0.6280	15.81	11.10	13.00	0.2247	0.2222
	16/9/2014	0.2967	2.3188	16.00	15.10	72.00	1.0107	0.1658
	30/9/2014	0.3383	3.5588	40.00	7.40	140.67	1.6074	0.1753
P3	19/8/2014	0.3333	0.5314	12.45	16.80	17.67	0.2370	0.1223
	6/9/2014	0.5000	0.6602	15.81	10.70	20.00	0.2823	0.2152
	16/9/2014	0.3102	1.8357	40.00	10.00	38.33	0.9490	0.2111
	30/9/2014	0.2583	0.5797	20.00	7.50	128.67	1.1794	0.1698
P4	19/8/2014	0.4159	0.4509	24.90	20.70	39.33	0.2370	0.1273
	3/9/2014	0.5600	0.6280	8.06	9.90	52.67	0.3358	0.2272
	16/9/2014	0.3237	1.1272	20.00	17.60	3.67	0.4716	0.1827
	30/9/2014	0.1804	2.9630	40.00	8.30	97.33	1.0807	0.2757
P5	19/8/2014	0.4722	0.7729	29.05	20.40	23.00	0.1918	0.1373
	3/9/2014	0.2800	0.6441	141.13	13.90	35.33	0.2782	0.2322
	16/9/2014	0.2500	0.5153	16.00	18.50	13.33	0.2370	0.1267
	30/9/2014	0.2271	1.3849	36.00	13.10	27.67	0.4305	0.2580
P6	19/8/2014	0.8438	0.8696	58.10	10.10	40.67	0.1835	0.0874
	3/9/2014	0.9800	1.0467	56.45	3.80	31.33	0.3399	0.2371
	16/9/2014	0.3154	0.8857	48.00	13.30	21.33	0.4881	0.1317
	30/9/2014	0.2915	1.0950	60.00	10.40	46.67	0.4099	0.2909

Table A15 Water flow rate for Melaka River

Location	Water Flow Rate (m^3/s)		
	S2	S3	S4
M1	NA	NA	NA
M2	0.147	0.150	0.175
M3	0.109	0.180	0.044
M4	0.126	0.180	0.065
M5	0.011	0.160	0.049
M6	0.084	0.030	0.005
M7	0.005	0.080	0.222
M8	0.035	0.140	0.036
M9	1.203	0.197	0.086
M10	0.044	0.090	0.787
M11	0.684	0.400	0.872
M12	0.949	0.370	0.376
M14	0.848	NA	NA
M15	0.274	0.410	0.444
M16	0.244	0.360	0.544
M17	0.293	0.140	0.336
M18	0.353	0.670	0.627
M19	0.392	0.020	0.178
M20	0.301	0.110	0.166

Table A16 Water flow rate for Durian Tunggal River

Location	Water Flow Rate (m^3/s)		
	S2	S3	S4
DT1	0.353	0.150	0.025
DT2	0.075	0.060	0.060
DT3	0.240	0.100	0.088
DT4	0.108	0.160	0.174
DT5	0.045	NA	0.060
DT6	0.167	0.160	0.041

Table A17 Water flow rate for Cheng River

Location	Water Flow Rate (m^3/s)		
	S2	**S3**	**S4**
C1	0.676	0.180	0.199
C2	0.129	0.070	0.156
C3	0.249	0.020	0.068
C4	0.066	0.050	0.029
C5	0.051	0.070	0.036
C6	0.052	0.040	0.042

Table A18 Water flow rate for Putat River

Location	Water Flow Rate (m^3/s)		
	S2	**S3**	**S4**
P1	0.066	0.147	1.763
P2	0.114	0.094	1.752
P3	0.063	0.033	1.570
P4	0.291	0.013	0.848
P5	0.339	0.454	0.309
P6	0.034	0.023	0.062

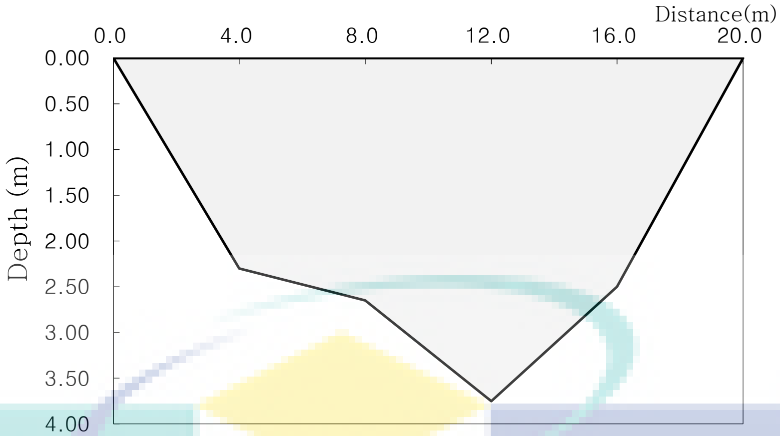

Figure 5.1A A cross-section of M2 at Melaka River

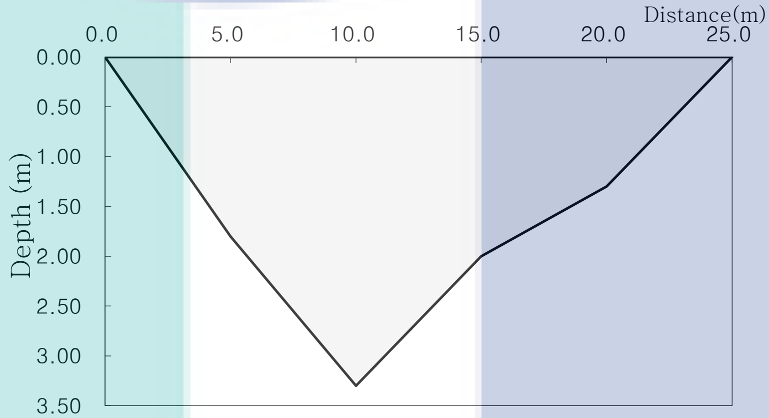

Figure 2A A cross-section of M3 at Melaka River

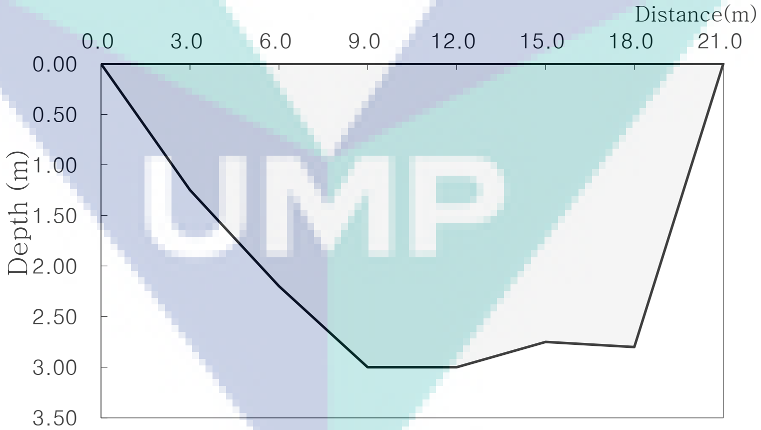

Figure 3A A cross-section of M4 at Melaka River

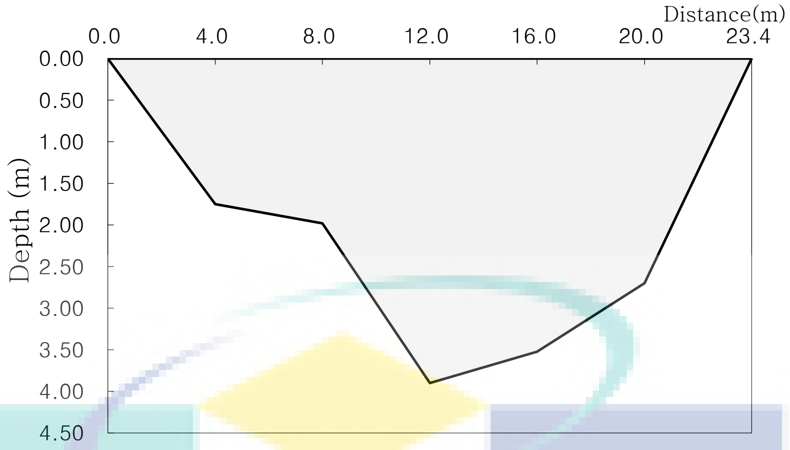

Figure 4A A cross-section of M5 at Melaka River

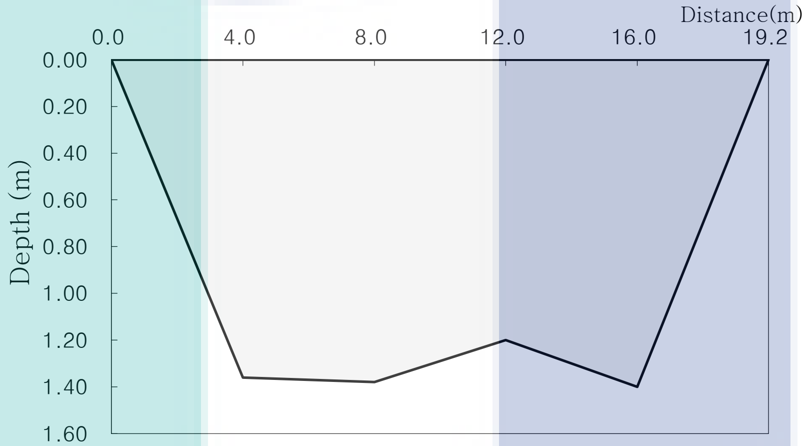

Figure 5A A cross-section of M6 at Melaka River

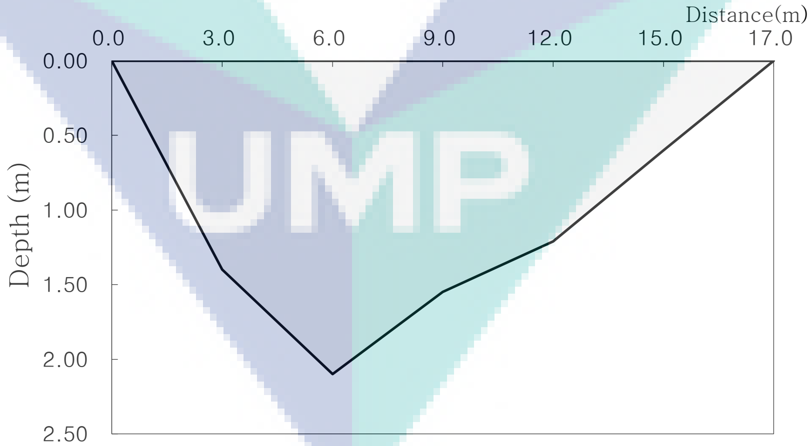

Figure 6A A cross-section of M7 at Melaka River

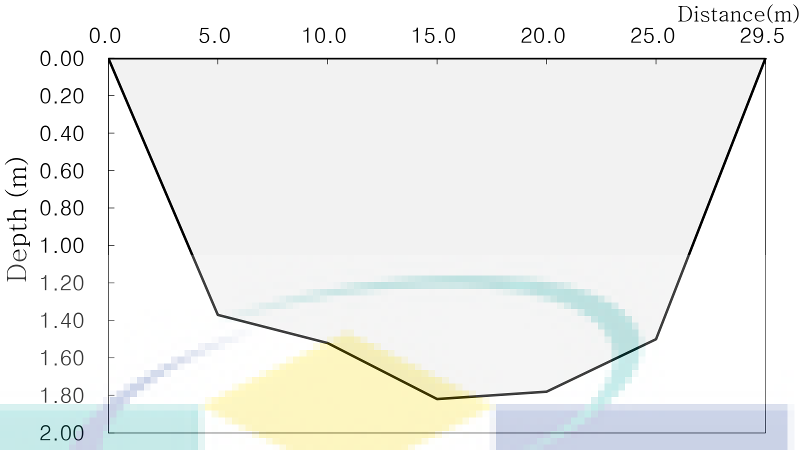

Figure 7A A cross-section of M8 at Melaka River

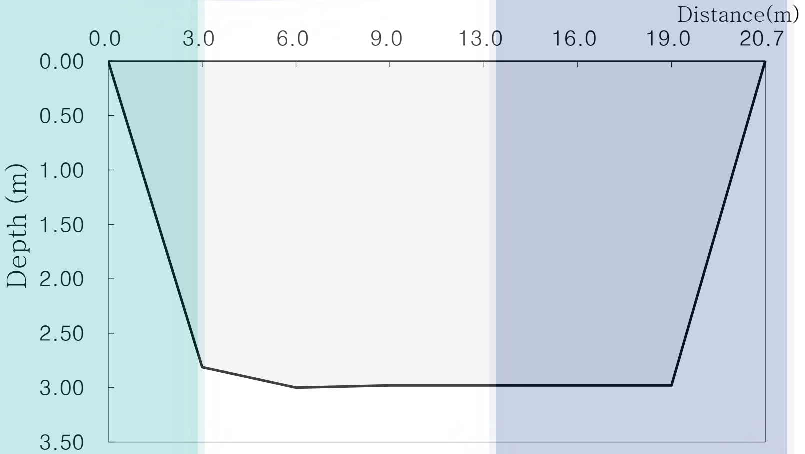

Figure 8A A cross-section of M9 at Melaka River

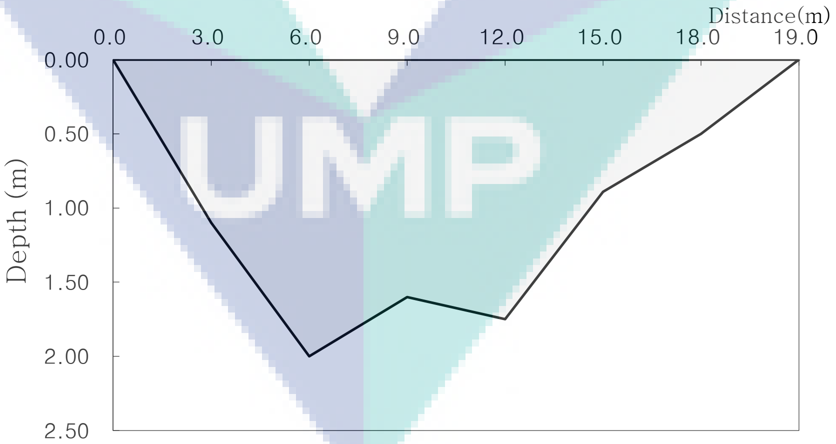

Figure 9A A cross-section of M10 at Melaka River

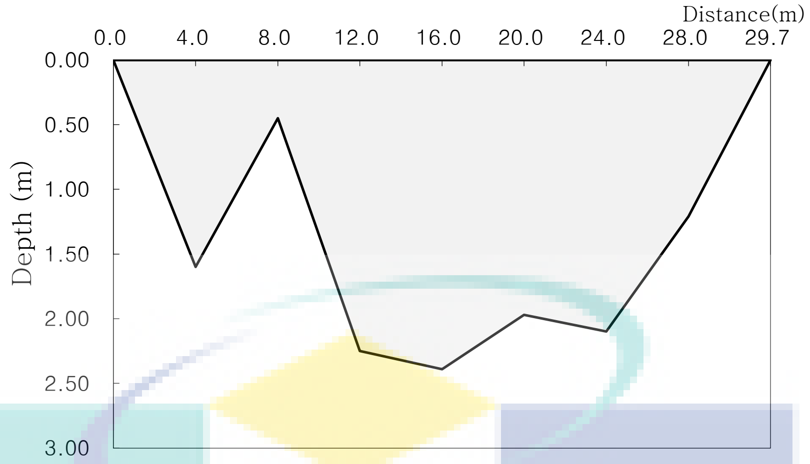

Figure 10A A cross-section of M11 at Melaka River

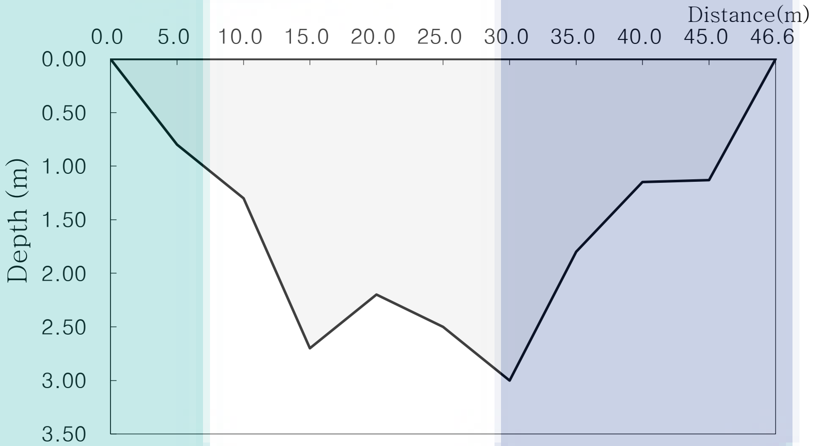

Figure 11A A cross-section of M12 at Melaka River

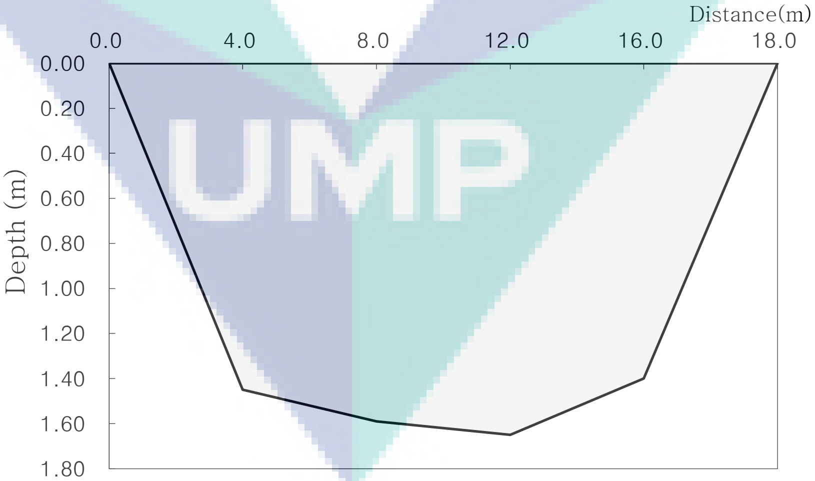

Figure 12A A cross-section of M15 at Melaka River

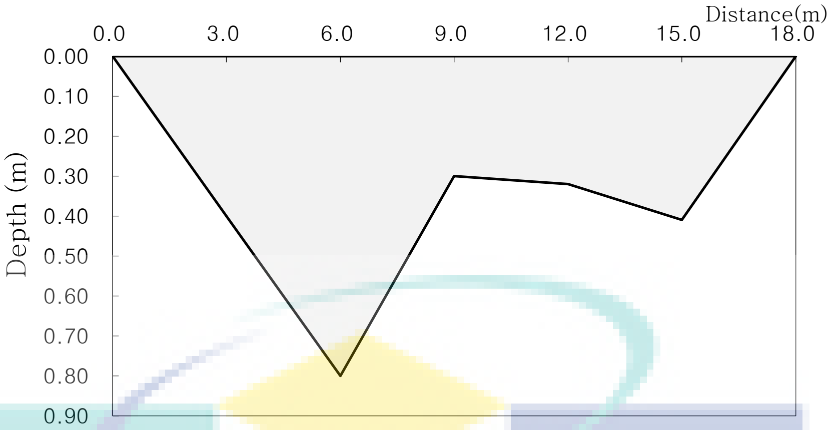

Figure 13A A cross-section of M16 at Melaka River

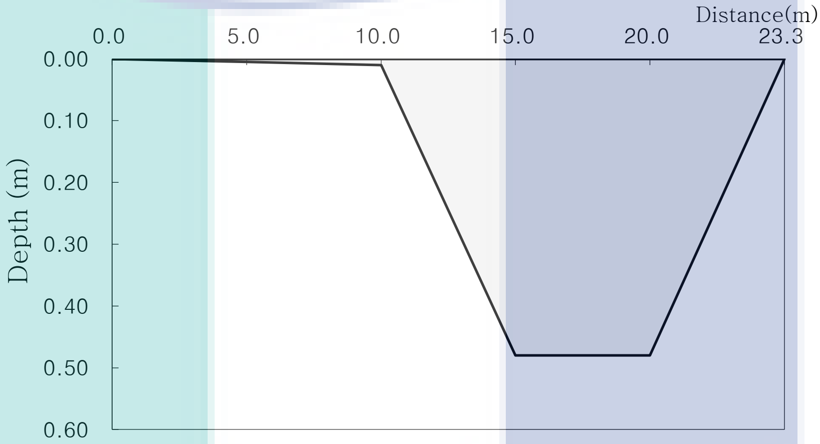

Figure 14A A cross-section of M17 at Melaka River

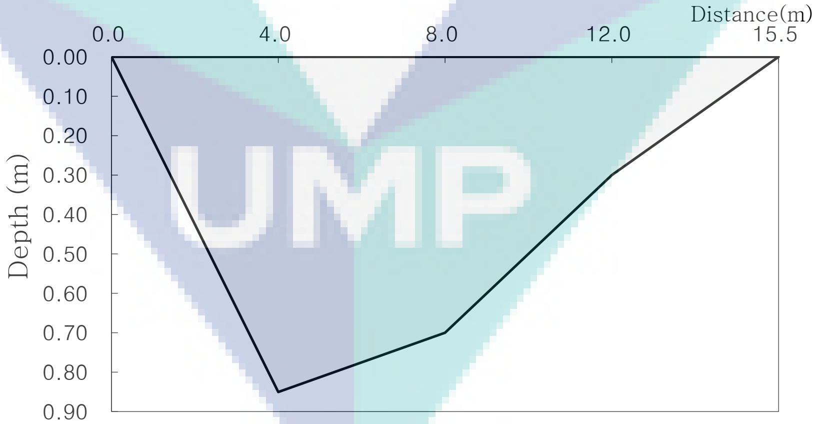

Figure 15A A cross-section of M18 at Melaka River

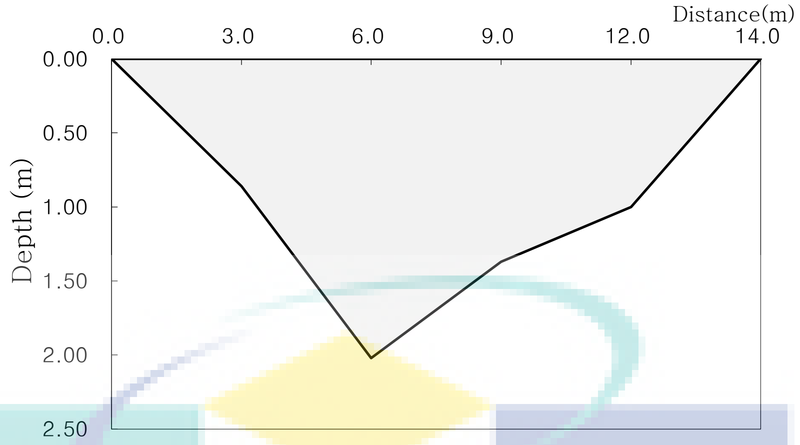

Figure 16A A cross-section of M19 at Melaka River

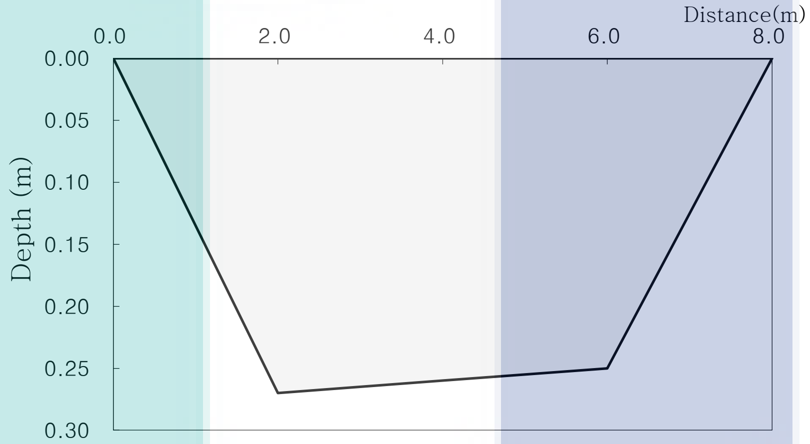

Figure 17A A cross-section of M20 at Melaka River

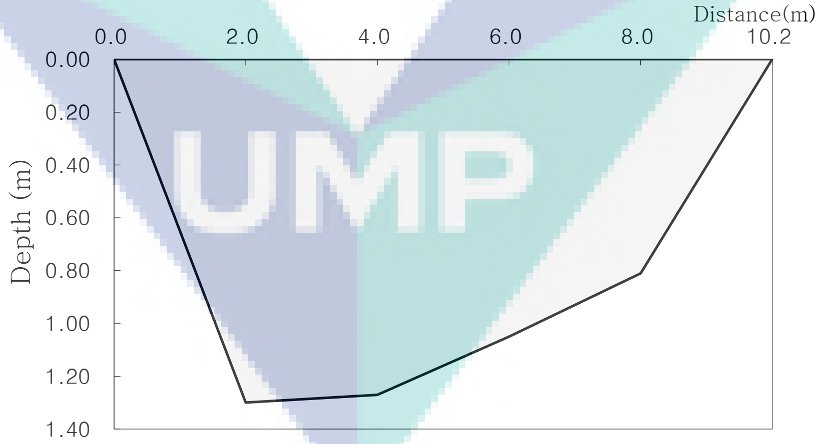

Figure 18A A cross-section of P1 at Putat River

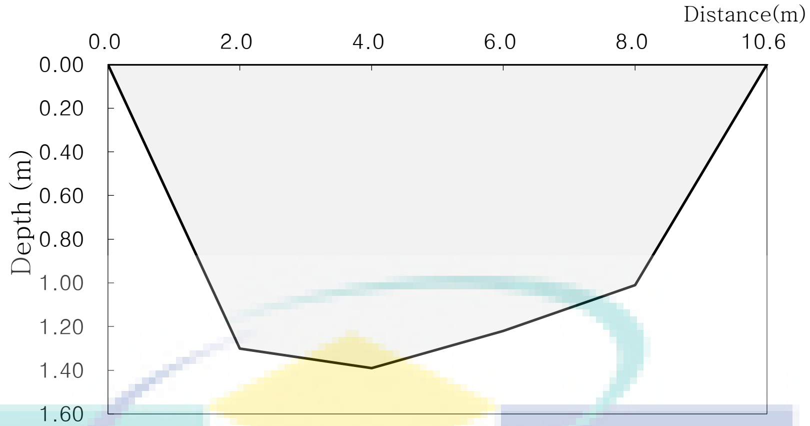

Figure 19A A cross-section of P2 at Putat River

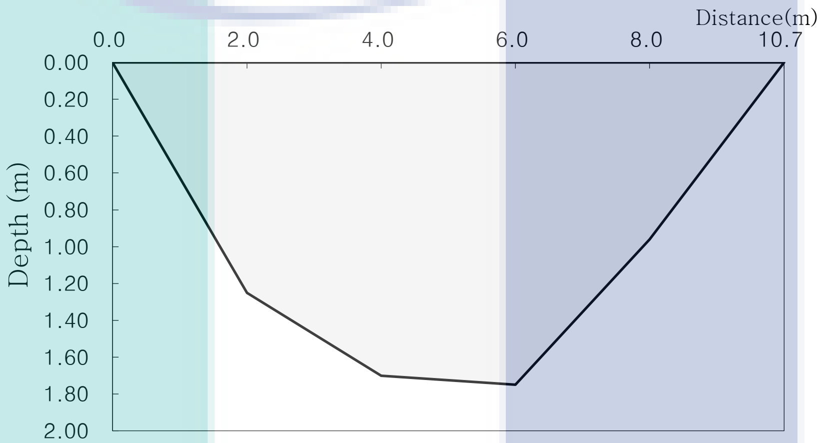

Figure 20A A cross-section of P3 at Putat River

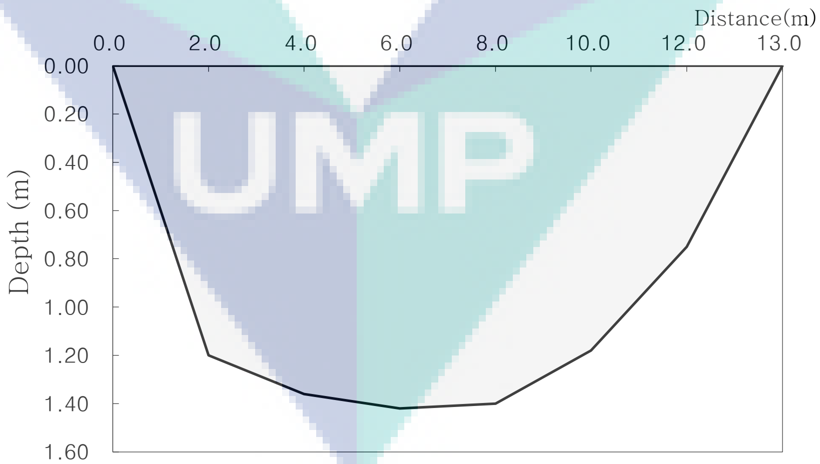

Figure 21A A cross-section of P4 at Putat River

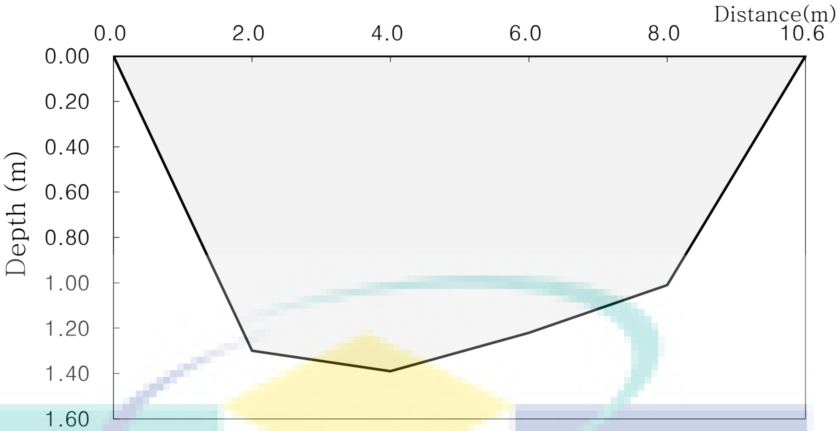

Figure 22A A cross-section of P5 at Putat River

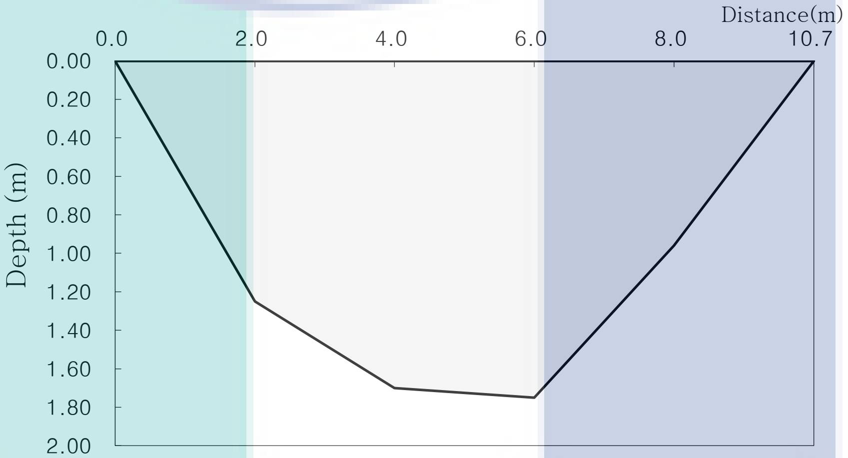

Figure 23A A cross-section of P6 at Putat River

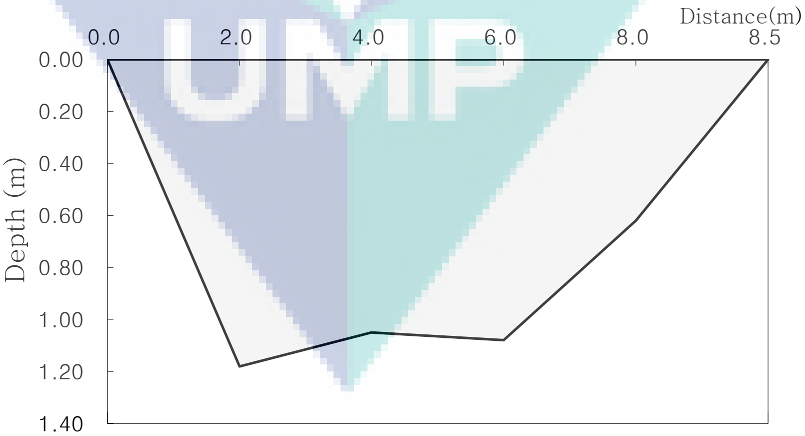

Figure 24A A cross-section of C1 at Cheng River

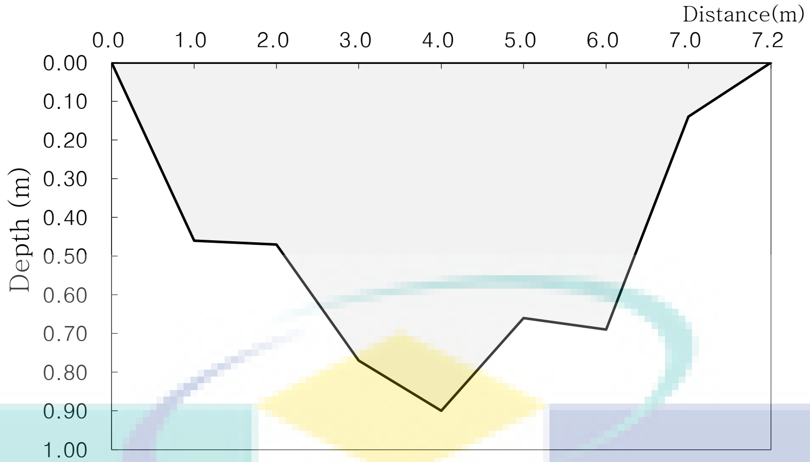

Figure 25A A cross-section of C2 at Cheng River

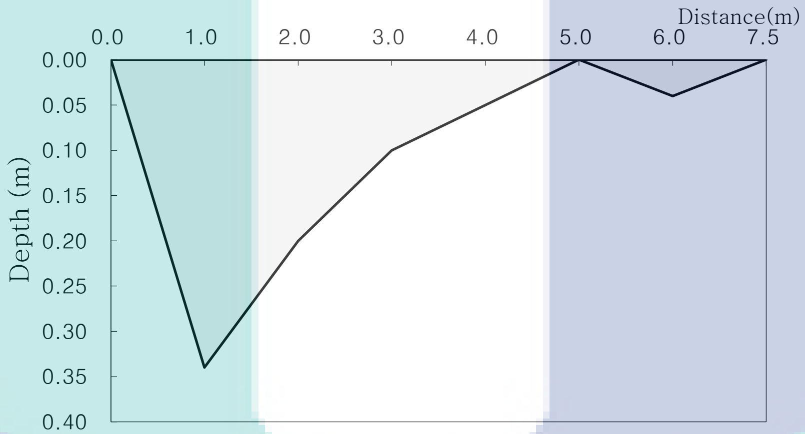

Figure 26A A cross-section of C3 at Cheng River

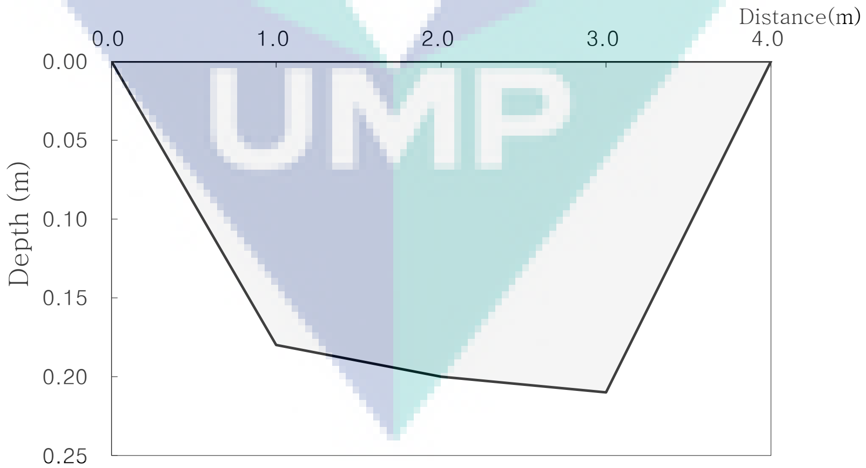

Figure 27A A cross-section of C4 at Cheng River

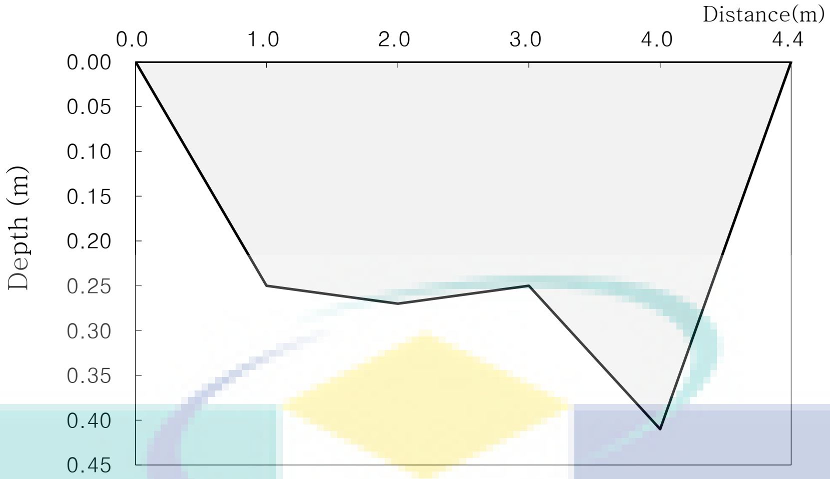

Figure 28A A cross-section of C5 at Cheng River

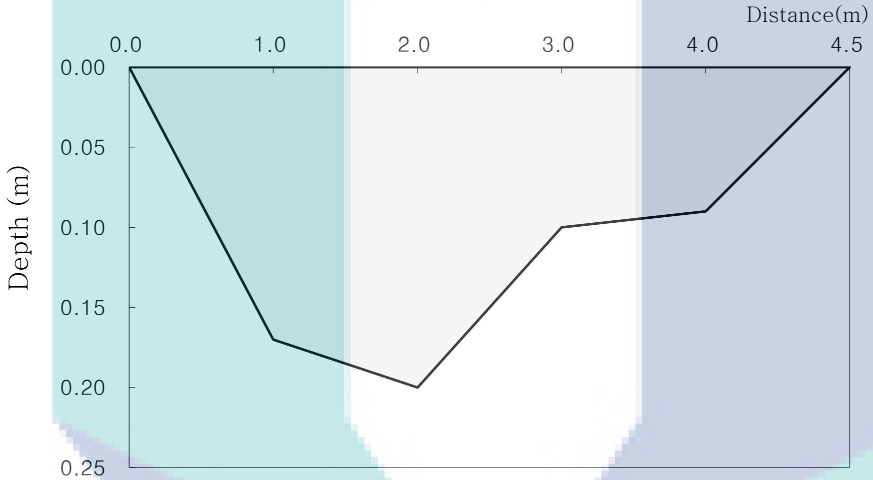

Figure 29A A cross-section of C6 at Cheng River

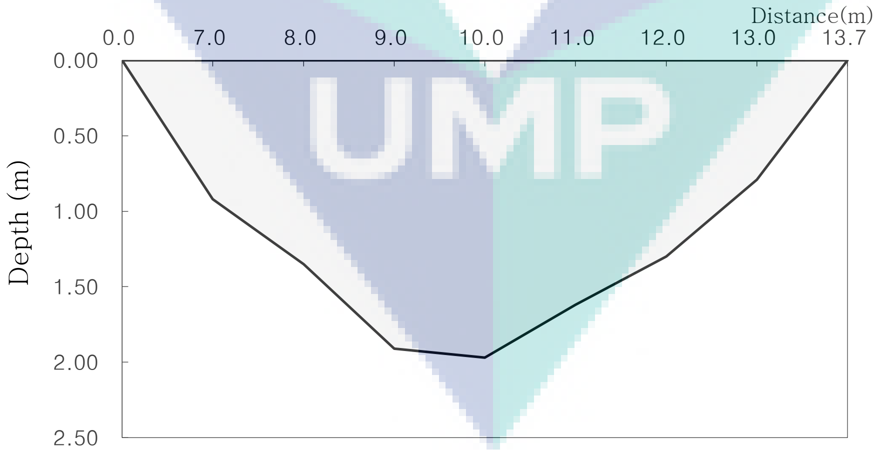

Figure 30A A cross-section of DT1 at Durian Tunggal River

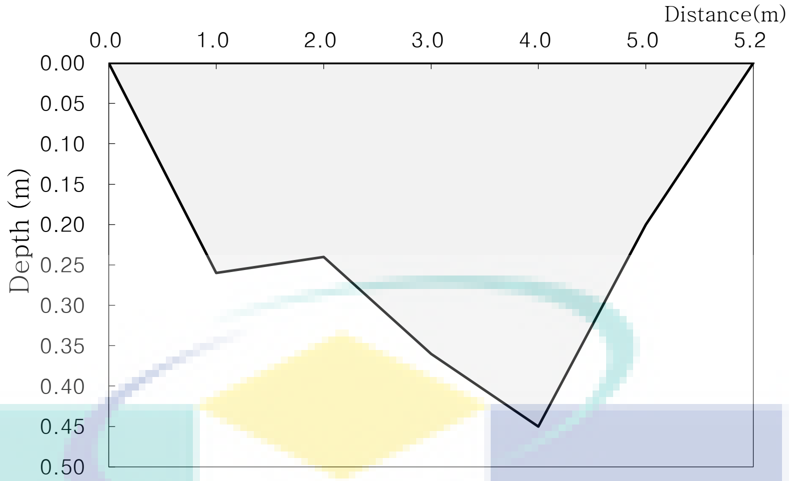

Figure 31A A cross-section of DT2 at Durian Tunggal River

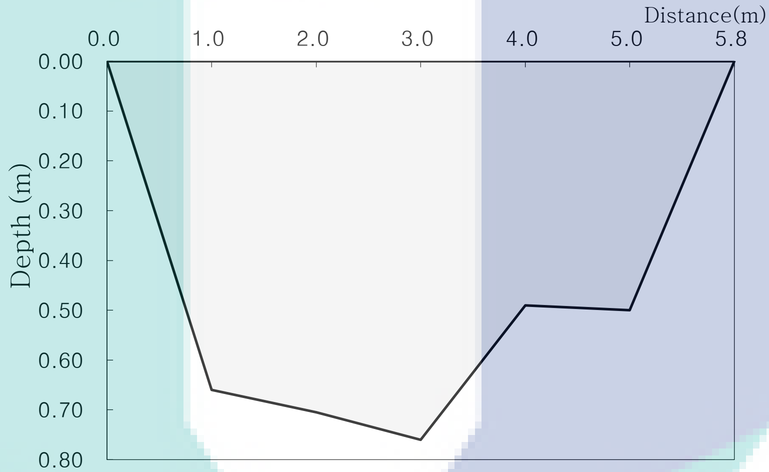

Figure 32A A cross-section of DT3 at Durian Tunggal River

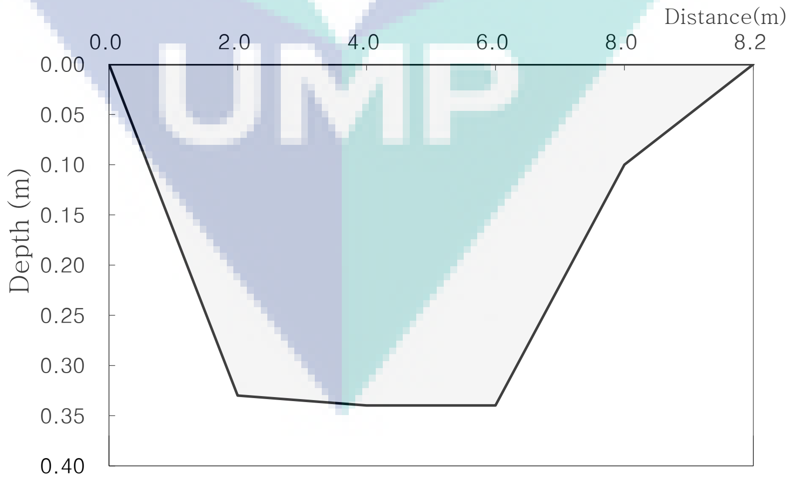

Figure 33A A cross-section of DT4 at Durian Tunggal River

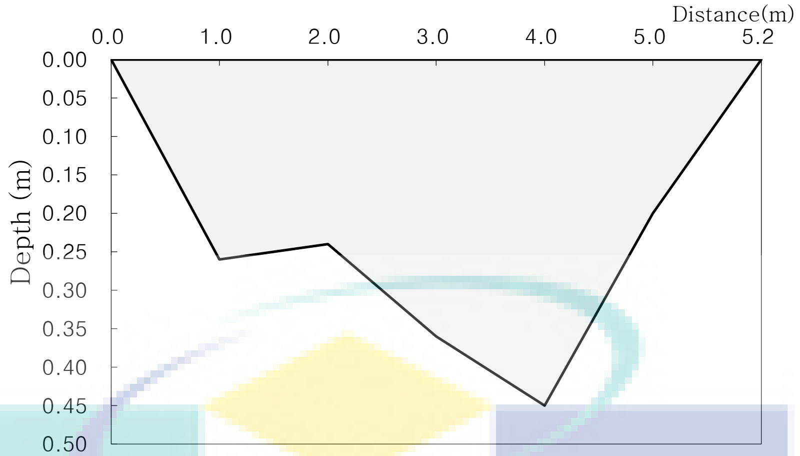

Figure 34A A cross-section of DT5 at Durian Tunggal River

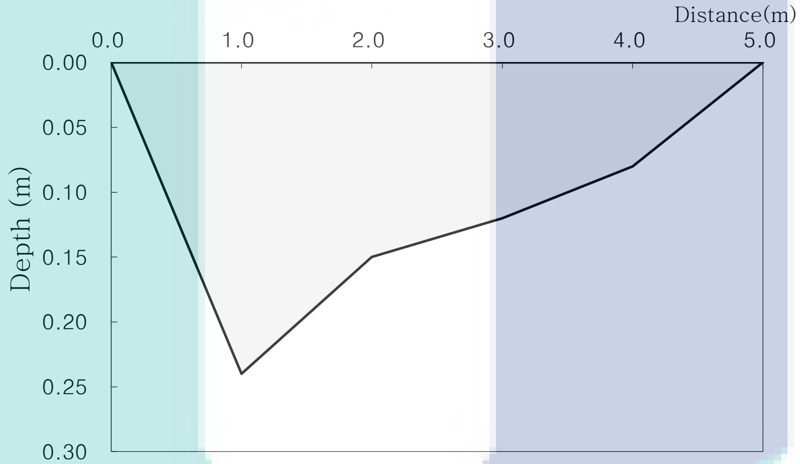

Figure 35A A cross-section of DT6 at Durian Tunggal River

APPENDIX B

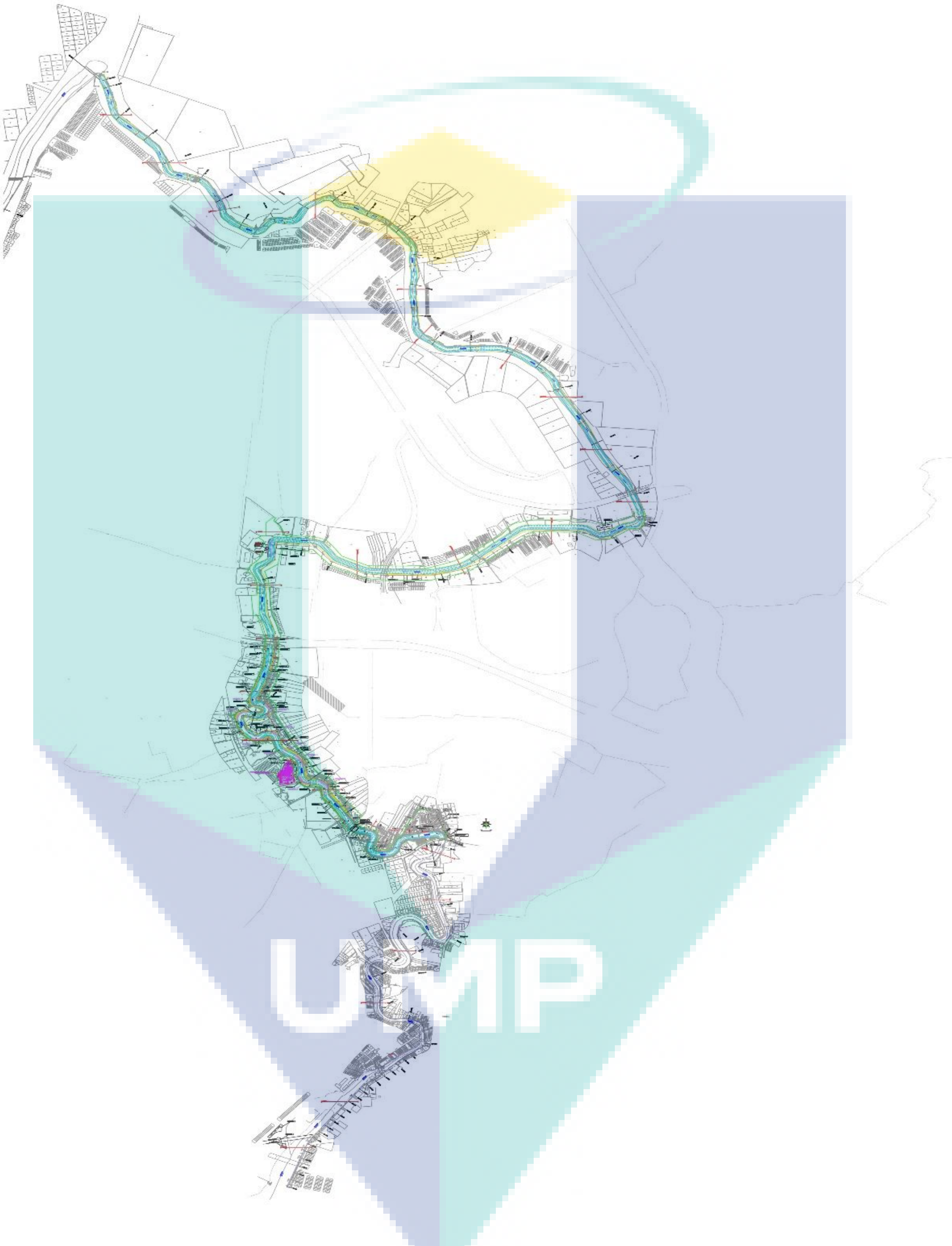

Figure 1B Melaka River Layout (Estuary to Malim).

APPENDIX C

Table 1C National Water Quality Standards for Malaysia (INTERIM)

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
BOD	mg/l	1	3	3	6	12	> 12
COD	mg/l	10	25	25	50	100	> 100
DO	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Color	TCU	15	150	150	-	-	-
Electric Conductivity	µS/cm	1000	1000	-	-	6000	-
Odor	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total dissolve solids	mg/l	500	1000	-	-	4000	-
Total suspended solids	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-
Fecal coliform**	count/ 100 ml	10	100	400	5000 (20000)a	5000 (20000)a	-
Total coliform	count/100 ml	100	5000	5000	50000	50000	> 50000

Table 2C Water classes and uses

CLASS	USES
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III - Common,of economic value and tolerant species;livestock drinking.
Class IV	Irrigation
Class V	None of the above.