UNIVERSITI PUTRA MALAYSIA

ENVIRONMENTAL FLOW ASSESSMENT OF HIGH GRADIENT RIVER SYSTEM USING INTEGRATED HABITAT SIMULATION ME

HASRUL HAZMAN BIN HASAN

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ENVIRONMENTAL FLOW ASSESSMENT OF HIGH GRADIENT RIVER SYSTEM USING INTEGRATED HABITAT SIMULATION METHOD

By

HASRUL HAZMAN BIN HASAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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ENVIRONMENTAL FLOW ASSESSMENT OF HIGH GRADIENT RIVER SYSTEM USING INTEGRATED HABITAT SIMULATION METHOD

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April 2017

Chairman : Nor Rohaizah Jamil, PhD
Faculty : Environmental Studies

River system has a paramount role to support various ecological functions apart from its crucial importance as the main water resource for man-related activities. Despite of its countless benefits to various river developments and uses, the integrity of the river shall never be compromised to ensure the resource sustainability and balanced ecosystem. The increase in multisector's water demand has lead to various river-uses issues with no exception of conservation and economic development perspective. The environmental flow assessment serves as a crucial first step in determining the alteration level that a river can withstand before it gets malfunctioned. This study adopted the combined methods of the hydrologic index, hydraulic rating and habitat simulation method for the environmental flow assessment of a high gradient tropical river system in Mid Perak State of Malaysia, namely Pelus River. There were two main objectives of the study; i) to correlate the by-seasons flow regimes and river physical habitat characteristics for Habitat Suitability Curve (HSC) development of the bioindicator species (*Barbodes binotatus*), and ii) to propose the river physical habitat and river flow tolerance range for different river management options and implications. Apart from the 30 years hydro-climatic secondary data, three sets of primary data representing normal, dry and wet seasons have been used as the main data source to increase the accuracy of the final result. The standard procedure of data sampling and processing were applied in accordance to established procedures including APHA and DID Malaysia guideline. Three HSCs of the *Barbodes binotatus* have been successfully constructed for depth, velocity and substrate parameter, which suggesting different Area Weighted Suitability (AWS) of the bioindicator species. Different sets of river management options and its implication have been proposed by fully-utilise the information of the tolerance range of specific flow and physical habitat characteristics to satisfy the different level of environment flow requirement. The environmental flow for a river system should be able to meet the agreed objective of the river uses set forth, and the implication must be well understood by the river stakeholders before a project can be conducted.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENILAIAN LUAHAN ALAM SEKITAR UNTUK SISTEM SUNGAI BERKECERUNAN TINGGI MENGGUNAKAN INTEGRASI KAEDAH SIMULASI HABITAT

Oleh

HASRUL HAZMAN BIN HASAN

April 2017

Pengerusi : Nor Rohaizah Jamil, PhD
Fakulti : Pengajian Alam Sekitar

Sistem sungai penting untuk menyokong pelbagai fungsi ekologi selain sebagai sumber air utama untuk aktiviti manusia. Walaupun terdapat banyak manfaat untuk pelbagai pembangunan dan penggunaan sungai, integriti sesebuah sungai tidak boleh dikompromi untuk kelestarian sumber dan ekosistem yang seimbang. Peningkatan permintaan air telah membawa kepada pelbagai isu penggunaan sungai termasuklah daripada perspektif pemuliharaan dan pembangunan ekonomi. Penilaian luahan persekitaran penting sebagai langkah pertama dalam menentukan tahap perubahan sungai yang mampu ditampung sebelum kehilangan keseimbangan fungsi. Kajian ini menggunakan gabungan tiga kaedah penilaian iaitu gabungan indeks hidrologi, penilaian hidraulik dan kaedah simulasi habitat fizikal untuk penilaian luahan persekitaran sistem sungai tropika cerun tinggi di Perak Tengah, iaitu Sungai Pelus. Terdapat dua objektif utama kajian ini iaitu; i) untuk mengaitkan ciri-ciri rejim aliran mengikut musim dan habitat fizikal sungai untuk membentuk Keluk Kesesuaian Habitat (HSC) bagi spesies bioindikator (*Barbodes binotatus*), dan ii) mencadangkan julat toleransi perubahan habitat fizikal sungai dan luahan sungai untuk pilihan pengurusan sungai yang berbeza serta implikasinya. Selain penggunaan data sekunder iaitu data 30 tahun bagi komponen hidro-iklim, tiga set data primer yang mewakili musim biasa, kering dan basah juga digunakan sebagai sumber data utama untuk meningkatkan ketepatan keputusan akhir kajian. Prosedur pensampelan dan pemprosesan data yang digunakan adalah mengikut prosedur yang ditetapkan termasuk garis panduan piawai APHA dan JPS Malaysia. Tiga HSC telah dibina untuk parameter kedalaman, halaju air dan substrat, yang digunakan bagi mendapatkan Pemberat Kesesuaian (AWS) bagi spesies bioindikator berkenaan. Pelbagai pilihan pengurusan sungai dan implikasinya telah dicadangkan dengan memanfaatkan maklumat berkaitan pada tahap berbeza mengikut julat toleransi luahan dan ciri fizikal sungai yang diperlukan. Luahan persekitaran sesebuah sungai sepatutnya dapat mencapai objektif penggunaan sungai yang telah dipersetujui, di mana implikasi bagi setiap pilihan penggunaan sungai dan kesannya mesti difahami dengan baik oleh pihak berkepentingan sebelum sesuatu projek boleh dijalankan.

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I certify that a Thesis Examination Committee has met on 20 April 2017 to conduct the final examination of Hasrul Hazman bin Hasan on his thesis entitled "Environmental Flow Assessment of High Gradient River System using Integrated Habitat Simulation Method" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Latifah binti Abd Manaf, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Wan Nor Azmin bin Sulaiman, PhD
Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Hj. Mohd Ekhwan Hj. Toriman, PhD
Professor
Universiti Sultan Zainal Abidin
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 August 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Nor Rohaizah Jamil, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Mohammad Noor Amal Azmai, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No.: Hasrul Hazman Bin Hasan, GS38767

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature: ____

Name of Chairman of
Supervisory Committee: Dr. Nor Rohaizah Jamil

Signature: ____

Name of Member of
Supervisory Committee: Dr. Mohammad Noor Amal Azmai

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℃	Degree Celsius
m/s	Meter per second
m^2/s	Meter square per second
m^3/s	Meter cubic per second
mg/l	Milligrams per litre
MSL	Mean Sea Level
NTU	Nephelometric Turbidity Unit
µS/cm	micro-Siemens per centimetre
AN	Ammoniacal Nitrogen
APHA	American Public Health Association
AWS	Area Weighted Suitability
BBM	Building Block Methodology
BOD	Biological Oxygen Demand
CASIMIR	Computer Aided Simulation of Habitat in Regulated Stream
CCA	Canonical Correspondence Analysis
CL	Confidence Limit
COD	Chemical Oxygen Demand
CSI	Combined Suitability Index
DEIA	Detailed Environmental Impact Assessment
DID	Department of Irrigation and Drainage
DO	Dissolved Oxygen
DOAA	Department of Orang Asli Affairs
DOAM	Department of Agriculture Malaysia
DOE	Department of Environment
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop Reserve Model
EF	Environmental Flow
EFA	Environmental Flow Assessment
EFR	Environmental Flow Requirement
EIA	Environmental Impact Assessment
EIA	Environmental Impact Assessment

ELOHA	Ecological Limits of Hydrological Alteration
EMC	Ecological Management Classes
FDC	Flow Duration Curve
GIS	Geographical Information System
H_2SO_4	Sulphuric acid
HDPE	High-density polyethylene
HEC-RAS	Hydrological Engineering Centre's – River Analysis System
HSC	Habitat Suitability Curve
IFIM	In-stream Flow Incremental methodology
IHA	Indicators of Hydrological Alteration
INWQS	Interim National Water Quality Standard
IRBM	Integrated River Basin Management
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resource Management
JRI	JPS River Index
MAM	Mean Annual Minimum
MAR	Mean Annual Runoff
NRCS	Natural Resource Conservation Service
NRW	Non-Revenue Water
NWQS	National Water Quality Standard
PHABSIM	Physical Habitat Simulation Model
REC	Recommended Ecological Category
RHABSIM	Riverine Habitat Simulation Program
RUSLE	Revised Universal Soil Loss Equation
RVA	Range of Variability Approach
RYHABSIM	River Hydraulic and Habitat Simulation
SEFA	System of Environmental Flow Analysis
SI	Suitability Index
SS	Suspended Solids
SZF	Stage of Zero Flow
TDS	Total Dissolved Solids
TNB	Tenaga Nasional Berhad
TSS	Total Suspended Solids

US	United States
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
WQI	Water Quality Index
WSL	Water Surface Level
WUA	Weighted Usable Area

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter discuss the natural functions of a river system including the natural ecosystem services and its role as the water resources to cater multisectoral needs. The chapter also emphasized on how the impairment to the river system integrity in a sense of the water quality, quantity and the wellbeing of the interdependent components could be impacted as the result of overexploitation. Unlike the conservative ideology of fully preserve the river system at its pristine condition permanently, the concept of environmental flow (EF) setting is being discussed to alternatively balance the needs between conservation and development of a river system. The discussion on the EF is setting prior to river development also being generally overviewed in line with the national Integrated River Basin Malaysia policy. The importance of the EF setting in Malaysia river system should be highlighted in the early stage of the river planning, to ensure the balance needs of various end-users and to defeat the changing global climate. The objective of the study and thesis organization was addressed in the end of this chapter.

1.2 River and Its Importance Function in Ecosystem Balance

A river is referring to a natural flowing watercourse that originates in the mountains and flow downwards until it reaches the base level, or commonly towards the ocean. A complex river system depends on the level of river order that forming several river tributaries before joining at the main channel. The morphometric characteristics of a river basin can be related directly to the flow regime pattern, by incorporating the different contributing factors of river inflow sources.

The upstream, middle and downstream reach of a river plays an equally important role in ensuring the continuity of the flow, ultimately to preserve the functions of all interdependent components within the system. Some of the provisioning ecosystem services provided by a river system are as tabulated in Table 1.1. Often disregards and wrongly perceived as permanently available free resources, the recent studies have revealed that the river system throughout the world has suffered the degradation through direct and indirect human influence (Palmer et al., 2009). River degradation and loss of freshwater biodiversity have major implication for human prosperity, health, water security and well-being because threaten from provision of ecosystem services. Table 1.1 shows the listed of provision ecosystem services provided by river system

Table 1.1: List of provisioning ecosystem services by river system

Provisioning ecosystem services	Supporting processes and structures	Effect of losing the ecosystem services
Water supply	The transport and storage of water throughout catchment.	Loss of water for human uses such as for residential, commercial and irrigation.
Water storage	Intact of floodplain and wetland.	Loss of groundwater, vegetation and wildlife.
Food production	Production of new plant and animal.	Reduction of food products from aquatic animal and plants. Shortages in fisheries sector.
Biodiversity	Intact of freshwater systems.	Loss of species and reduced of ecosystem resilience.

(Source: Adapted from Palmer et al., 2009)

1.2.1 Common Issues of River Threats In Malaysia

Major water issues affecting sustainable development in Malaysia were identified and explained by Chan (2003). The major issues must be addressed to ensure sustainability of our water resources for now and in the future development in Malaysia.

1.2.1.1 Over-Emphasis on Water Supply Management

The water management system in Malaysia employs and depends heavily on the water supply management approach to cater to demand. The greater the demand, the more water has to be supplied so more structures like dams, water treatment plants and water distribution pipes need to be built. This approach is unsustainable in the long run as water demand will eventually overtake water supply. Supply and water demand management has to be integrated. In addition, there is a need to look at water wastage and rates to change the appalling consumptive behaviour of most Malaysians towards water.

1.2.1.2 Institutional Issues

Malaysia lacks a central agency to manage the overall aspects of water resources management. Too many agencies have jurisdiction over different aspects of water management, leading to sectoral management of water and conflicting and competing objectives in Malaysia.

1.2.1.3 High Rates of Water Wastage

Rates of water wastage in domestic, industrial and agricultural use are very high and this is unsustainable in the long term. Compared to other countries, Malaysia uses and wastes too much water.

1.2.1.4 Changing Weather Patterns

Globally and locally, the climate and weather are changing and this is affecting water resources. *El Nino* happened in 1997 was brought severe drought resulting in water crises in many parts of Malaysia. Water planning and management agencies in Malaysia do not adequately take into account changes in weather patterns.

1.2.1.5 High Rates of Non-Revenue Water (NRW)

Rates of NRW in Malaysia are high with the national average being 40%. This equals a loss of 40 litres out of every 100 litres of treated water. If Malaysia can reduce the NRW losses to a minimum, the building of new dams could be delayed.

1.2.1.6 Privatization of the Water Sector

Water is considered a lucrative commodity and there are plans by the government to privatize water supply in almost every State. However, several water privatisation schemes have not produced desirable results. Water privatisation still lacks transparency and accountability in Malaysia.

1.2.1.7 Destruction and Degradation of Water Catchments

Many water catchments in the country have yet to be gazetted and protected. Consequently, they are exposed to development of all kinds resulting in adverse environmental effects, which ultimately make water resources unsustainable.

1.2.1.8 Legislation

Many existing laws are also not comprehensive enough and do not deal directly with water issues. Most legislation relating to water is outdated and needs to be reviewed in current context. The recently approved Water Services Industry Act and National Water Services Commission Act provide some progress towards strengthening water resources management. However, their scope is limited to matters concerning regulation of the water services industry involving mainly the treatment and distribution of water supply which is not focusing on water sustainability.

1.2.1.9 Water Pollution

Water pollution is a serious problem in Malaysia and impacts negatively on the sustainability of water resources. It reduces total water availability considerably as the cost of treating polluted waters is too high and in some instances, polluted waters are not treatable for consumption and aquatic ecosystem.

1.2.1.10 Low Water Rates

Water rates in Malaysia are amongst the lowest in the world. This has not encouraged water conservation but instead led to water wastage and overuse, both of which undermine the sustainability of water.

1.2.1.11 Inefficient Agricultural Water Use

Agriculture uses about 68% of total water consumption in Malaysia but irrigation efficiency is 50% at best in the larger irrigation schemes and less than 40% in the smaller ones. There is also no recycling of irrigated water. All of these factors challenge the sustainability of water resources in Malaysia.

1.3 River Management Practices and Planning

Water resources must be developed and managed in a sustainable manner to ensure the social, economic and environmental development of the current and future generations are not jeopardized. Because of the strong water-development linkage, and as water is a common factor that cuts across all sectors of development, monitoring the sustainability of water resources can effectively provide an indication of sustainable development in a country.

It is almost impossible to retain a river system at a pristine condition permanently. This is an evitable fact the country has to admit as Malaysia is still very much in a developing mode to achieve a more stable economic condition. Thus, natural resources including river system have no exception from the economic development planning of the country. Deemed as a resources-rich from domestic uses until power generation industry, river has being.

In Malaysia, environmental flows are not prescribed in the national legislation as framework laws. This approach becomes a part of the Detailed Environmental Impact Assessment (DEIA), which is to be presented by the developers in their Water Protection Plans. Findings from an environmental modeling flow study are important in managing the river (at least Class II) after river diversion project (Toriman, 2010). For example, during drought, water in a catchment may affect certain species that have particular requirements such as spawning, riparian germination, and habitat availability (Maidment, 1993).

However, water use also does not have significant impacts on the ecological processes in a river diversion section. It is become critical to set the environmental flows during the planning stage of a project to ensure that this value is adhered to during the diversion operations. There is also a need for reporting low flow confidence limits and how these values are used in the decision making process. A case study in Pelus River has proven that EFA is a good exercise to identify acceptable limit threshold for the tunnel construction and at the same time, maintaining the river water level for biotic and abiotic life forms along the river system (Toriman, 2010).

According to the World Conservation Union (IUCN), environmental flow can be described as the most important factor in integrated water resources management (Dyson *et al*., 2003). The required amount, rate, and quality of water flows to sustain freshwater ecosystem also define an environmental flow (Martinet, 2009). In-stream flow, environmental allocation, and ecological flow requirement are similar with the term 'environmental flow. Basically, environmental flows are the flows of water in rivers and streams that are necessary to maintain healthy aquatic ecosystem. The environmental flows are designed to ensure natural conditions of the rivers.

Based on Tharme (2003), environmental flow assessment and maintenance are relatively new practices for the water sector, particularly in developing countries. There is still lack of awareness regarding this concept and its application. Most countries especially in developing countries do not have any environmental flow legislation or accepted approaches for the assessment of these flows. Existing developed assessment methods are either not known or rarely applied. The data for developing these methods and the required expertise to implement this concept are limited with poorly documented relevant ad-hoc studies and initiatives (Mazvimavi et al., 2007). Thus, environmental flow assessment is considered to fulfill the objective of meeting human demand on water resources and at the same time, maintaining ecological integrity (Tharme, 2003).

Water is an important medium for any ecosystem in the world, both in qualitative and quantitative terms. As known, the sources of water are the rivers, lakes, and sea. Reduce in water quantity and deteriorating water quality pose serious negative impacts on the ecosystems, especially to humans and aquatic life forms (Richter et al., 1996). Therefore, the need to preserve and be aware of the significance of water sources is essential. Environmental flow assessment has always been considered to monitor human activities such as impoundment, diversions, groundwater exploitation, and use of water for hydropower generation, and catchment land-use, which will change the flow regime (Baron *et al*., 2002). In some other countries such as Australia, United States, and Canada, environmental flow assessment is already made compulsory in their environmental impact assessment (EIA) for project development involving water withdrawal in aquatic ecosystems (Dyson *et al.,* 2003).

1.4 River Flow Regimes

Ecologists identified five ecologically relevant characteristics of natural river flow regimes which include magnitude, frequency, timing, duration and rate of change of hydrological condition (Poff et al., 1997). These flow regimes can be used to characterize the entire range of flows and specific hydrological events such as low flow and floods that are critical to the biota and ecological functioning of river ecosystems. Aquatic life has survival under the natural flow regimes in river based on these characteristics.

According to Richter (2003), magnitude of flow is the most crucial on ecological processes in river ecosystems. Flow magnitude or as discharge is the amount of water moving past a fixed location per unit of time. Magnitude can refer to the quantity of flow that relative to the some river properties, such as the volume of water needed to provide an adequate water depth in river for fish passage. The highest magnitude of flow can inundate shallow biota habitat and alter the geomorphological structure of river.

The frequency of flow is to show how often flow of given discharge occurs over time period. The frequency for any particular flow magnitude is shown by a flow duration curve such as low flows and high flows. The flow duration is the length of time or period associated with a particular discharge events such as low flow period that lasts for days to several months.

Timing of flow is refer to the season in year when a particular event to occur such as fish migration or spawning. Floods that occur in tropical rivers have a predictable annual flood to many fish migration (Welcomme et al., 2006). The rates of change of hydrological condition refer to the rate of stream discharge changes from one magnitude to another. One major factor is precipitation which usually contributes to high river flows. The sudden rainstorms and depending on the catchment characteristics, storm flow may take a faster route to the stream channel.

Restoring biodiversity and ecosystem function become global imperatives for river managers and ecologist (Palmer et al., 2008). This need further understanding on the holistic concept of the ecological roles of natural hydrologic and other environmental regimes, the interactions in flow regimes, and the manage the freshwater ecosystem in order to achieve the greatest benefits for human and nature.

The dynamic freshwater ecosystems consists of five major environmental drivers; flow regime, water quality, biotic assemblage, functional aquatic ecosystems, short-term goods and services, and long-term sustainability and adaptive capacity (Baron et al., 2002).

All five dynamic environmental factors display natural condition for annual variation according to seasonal patterns in climate condition such as precipitation, temperature and day length. The water regime is a major factor that regulates the structure and functioning of aquatic ecosystem. Inputs of sediment and organic matter, nutrients, light and temperature will interacted with flowing water to create and sustain physical habitat structure to biota ecosystems.

1.5 Problem Statement

The biota and aquatic ecosystems have varied naturally over millennia years in accord with climate cycles and environmental regimes. Nowadays, with the rise of human populations around the world were directly and indirectly affects the aquatic ecosystems and alter the five dynamic environmental factors drives. Globally, more than 83% of the land surface has been significantly influenced by the human footprint and become increasingly increase year to year (Sanderson et al., 2002).

Threats to aquatic ecosystems begin in their catchments area with alterations to the hydrological cycle and the materials carried by water those threats to surface water and groundwater systems (Naiman et al., 2008). Water as effective vector for physical, chemical and biological effects of stressors that freshwater have been highly modified around the world.

The alteration to the natural functioning catchments and aquatic ecosystems can be categories into five major threats were shown in Figure 1.1. Habitat degradation and the presence of non-native species are often cited as major contributors to loss of freshwater biodiversity such as fish diversity (Magurran, 2009). Water quality of running water ecosystems is determined by the geology, climate and human activities in catchment areas.

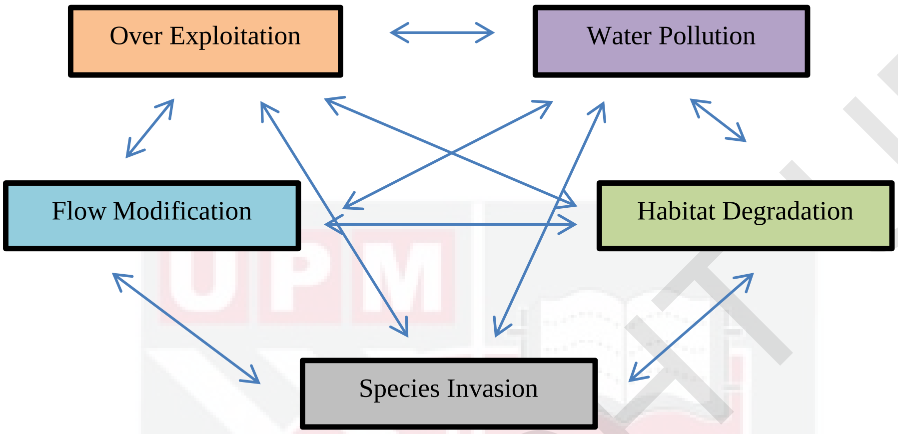

Figure 1.1: The five major threat categories and interactive impacts on aquatic biodiversity. (Source: Dudgeon et al., 2006)

Human activities or anthropogenic have modified the natural hydrologic and ecological processes of catchment and river systems for thousands of years (Boon et al., 1992). Lots of documented of geomorphology, hydrology and ecological impacts of deforestation, agricultural and urbanization on river system (Allan, 2004).

Land use change for agricultural activities may adversely affect freshwater ecosystems by reduction of catchments area, altered pattern of runoff, increased of soil erosion and also elevated nutrient levels. Removal of native forest vegetation by conversion of forests to agricultural lands can decrease soil infiltration and often result in increased overland flow and headward erosion of stream channels (Poff et al., 2006).

Land use change can reduce retention of water in catchment soils and will route it quickly to downstream, increasing the frequency of floods and reducing the base flow levels during dry periods (Poff et al., 1997). These changes increase the temporal variation of abiotic factors and degrade water and river habitat quality in catchments.

The unpredictable flow regimes such as flashy flood and lower dry season flows are potentially detrimental to aquatic species adapted to particular patterns of flow variability (Pusey et al., 1993).

Urbanization development on catchment area was created vast areas of impermeable surface that water flow direct away from subsurface pathways to overland flow and into the nearest river systems. Consequently, river flows will increase in velocity and become flashier and unpredictable which cause floods increase in frequency and intensity (Walsh et al., 2005).

The unpredictable river flows can enhance the rate of invertebrate drift and decline in benthic diversity and also the food resources of fish. These cumulative effects become worse in the lower reaches of river systems. The changes in catchment land use, channelization and urbanization can alter the energy budget and thermal capacity, and their flow regimes of river systems which are these two processes may have synergistic effects. The unstable conditions of flow regimes variability may have severe consequences for aquatic species and their functional ecosystems that depend on the rate of change in discharge relative to the adaptive capacity of species (Olden and Naiman, 2010).

The increasing population will increase demand on water supply and thus increase water withdrawal in aquatic ecosystems. Hence, it will give impacts on damage river systems and also catchment functions. Human population depends on freshwater and resources within their life. Freshwater ecosystems provide water for drinking, irrigation, transportation; generate hydropower and source of foods. These factors has will increase demand on water utilization and withdrawal of freshwater that alter the balanced of river flows.

Nowadays, as the increase in human population and development project the demand for water is increasing, especially in industrial and agriculture sector. However, due to the several factors that continuously pollute the rivers, it may degrade the river water health (Amneera et al., 2013). In the years 2005 and 2006, with increases the price of fuel almost double sees the replacement source for the electrical generation of fuel to the hydro power.

Despite dams are one of the alternatives for proper management of freshwater resource, leading to increase the development of socioeconomic but it is also degrading the river water quality and change the habitat of aquatic life (Dudgeon et al., 2006). According to United Nations Environment Program (2003), dams may also contribute to the change of downstream flow, decreased water quality, increased in-lake suspended sediment, river bank flushing, obstructs movement of migratory species and decreases of aquatic biodiversity.

Rapid development project in Malaysia may degrade the water quality and quantity of the river. Tenaga Nasional Berhad (TNB) is planning to build a mini hydroelectric dam as an alternative source of continuing and sustainable supply of electricity at Pelus River catchment. Any construction of a mini hydroelectric dam can change the surface hydrology of the catchment, as well as gives the impact on water quality and also effect to the habitat of aquatic life (Hansen et al., 1995). Not only that, it may degrade hydrological properties of river due to increasing of the sediment load. Unhealthy water quality may cause disturbance to the natural ecosystem, affecting the food chain, and can degrade the population of aquatic life and wildlife.

Mini-hydroelectric power plant can be designed for small-scale on existing rivers that categorical as a small and cascade river channel. It could be beneficial in the usage of all existing water reservoirs and streams as to generate hydro power which is renewable in nature. By this, mini-hydroelectric power plant does not come across the problems of reclamation of man and environmental problems related to the large hydro power plants (Adhau et al., 2012). Despite, of it has almost no impact toward environment, the alteration and improper technique could cause the damage to fish as well as change the river flow in downstream (Oliver, 2002).

Recently, the importance of the natural hydrologic regime to the functioning of freshwater ecosystems that provide needed goods and services for human uses and maintenance of biodiversity is increasingly well recognised. Environmental flow assessment is seen can fulfil to balance on freshwater ecosystems and at the same time maintaining ecological integrity (Dyson et al., 2003).

The balancing of requirements of the aquatic organisms and other uses is becoming critical issues in Malaysia as populations and associated water demands increase. But, the environmental flow assessment for freshwater dependent ecosystems represents major challenges due to the complexity of physical components and their interactions within others components in ecosystems.

Environmental flow assessment (EFA) is defined as a suite of flow discharge of flow magnitude, duration, timing and frequency. These flows ensure a flow regime capable of sustaining a complex set of aquatic habitats and ecosystem processes (Smakhtin & Eriyagama, 2008). EFA represent the ecologically acceptable flow regime and the issues of EFA are highly demand on the world agenda which is remains a new research field in Malaysia.

Thus, this study compliance with watershed planning strategy in integrated river basin management (IRBM) and integrated water resources management (IWRM) as environmental flow assessment (EFA) serve to represent water allocation for ecosystems. EFA is not exclusively a matter of sustaining the ecosystems but also to support human well-being especially in Malaysia. This study will incorporate hydrological analysis and modelling processes that can be used as a management tool in watershed planning.

1.6 Research Objectives

This study aims to identify the major factors that limit the target fish species population by focusing on the physical microhabitat analysis in conjunction to flow dependent function. The specific objectives for this study:

1. To correlate the by-seasons flow regimes and river physical habitat characteristics for Habitat Suitability Curve (HSC) development of the bioindicator species (*Barbodes binotatus*).

2. To propose the river physical habitat and river flow tolerance range for different river management options and implications.

1.7 Scope of Study

This study focusing on minimally altered high gradient river system, Pelus River, which has a high potential for river development in future. Environmental flow objective set forth for this river is to fairly accommodate the need for river development for local economic enhancement while keeping the functioning systems of the river in the most optimum condition to sustain the ecological importance.

Adopt the integrated combination method of environmental flow assessment namely hydrological rating, hydraulic index and physical habitat simulation. Modelling software developed by Aquatic System Analysis which is System of Environmental Flow Analysis (SEFA) has all three section of above mentioned methods, was used in this study to incorporate all the primary and secondary data of the study area. Numbers of fieldwork trips for primary data collection were successfully conducted to capture complete water year cycle, while 30 years of hydro-climatological data were obtained from the related agencies for long-term data analysis. Additional fish analysis and landuse changes study were conducted to comprehensively understand the selected biological and physical characteristics of the study area. The five components of river functions-enabled parameter were emphasized in this environmental flow assessment study, namely the flow magnitude, frequency, rate of change, timing, and duration.

At the end of the study, the Habitat Suitability Curve (HSC) which was developed specifically for the bioindicator species in the study area is being used as the benchmark for environmental flow setting of Pelus River. This HSC, which reflects the Area Weighted Suitability (AWS), proposes the optimum condition of the river characteristics that must be sustained in order to retain the target species in the system.

The extent of the river alteration that can be made in Pelus River is proposed in regards of river flow alteration and/or channel modification such as water abstraction, channel modification, impoundment and its impacts towards the target species specifically, and towards the river ecosystem in general.

By understanding the environmental flow requirement of the study area, a controlled and well-defined river uses can be planned carefully at the early stage of the river development. The proposed environmental flow requirement set for Pelus River is equally important for the stakeholders to decide the objective of the river uses in future, without neglecting the importance of ecological integrity conservation.

1.8 Significance of Study

This study focusing on the environmental flow assessment that consists of physical habitat characteristics of targeted freshwater fish species in Pelus River, Perak, Malaysia based on their optimum level. Thus, this study carried out the several components of environmental flow assessment such as hydraulic modelling and habitat modelling analysis for simulation methodologies.

This study adopted the System of Environmental Flow Analysis (SEFA) to identify the main factor that limits the fish population on freshwater ecosystem and their physical microhabitat analysis in conjunction to flow dependent function. River flow is major factor that strongly correlated with several critical physicochemical characteristics on river system such as river channel geomorphology and water quality which affect species habitat diversity on their distribution and abundance of riverine species.

In the end of this study, the Area Weighted Suitability (AWS) will be developed that can be related to important aspect of assessment of alternative for stream flow management. Other than that, habitat suitability curve (HSC) will be derived for the targeted freshwater fish species which is *Barbodes Bionotatus*. The specific habitat suitability curve for targeted freshwater fish species used as a benchmark for weighted usable area index based on the optimum level in the recommended flow regime.

The recommended of flow regimes derived from this study as a benchmark for stream flow management in the future. It could serve as important input for the recommendations and references to the local authorities and agencies that control in managing and maintaining the river ecosystem.

1.9 Thesis Organization

This thesis consists of five chapters, which provides hydrological, hydraulic and habitat data for the simulation model as well as their potential flow regime in the study area. The chapters in this thesis have been organized as follows.

CHAPTER 1 discusses briefly on the background of this study, problem statement, and the objectives of this study. Scope and significance of study are provided to provide better insights of this study**.** This chapter further introduces the physical habitat for freshwater fish species and the importance of freshwater fish. Besides that, this chapter discusses on the definition of environmental flow assessment and river functions.

CHAPTER 2 provides comprehensive literature review in relevance to this study. The review on related studies and current practices obtained from relevant journals or academic books provides a background to develop theory, methodology and research tools for this study. It focuses on the environmental flow assessment and the physical habitat characteristics influencing the abundance of freshwater fish.

CHAPTER 3 covers the study area and method employed in this study. The research methodology is based on sampling activities for obtaining primary data and secondary data is provided by selected agencies. It is divided into several parts including sample collection, sample analysis, data analysis, and modelling analysis for channel morphology measurement, water quality, and System for Environmental Flow Analysis. Therefore, this chapter provides detailed explanation on the methodology applied in this study.

CHAPTER 4 contains the results and discussion in this study. The hydraulic data and habitat data for the fishes from three sampling activities are provided with the results from statistical analysis and simulation model. The results obtained are presented in graphs and tables such as longitudinal profile, length-weight relationship, habitat suitability curve, and weighted usable area. Furthermore, this chapter provides findings with respect to the three objectives presented in this study.

CHAPTER 5 serves as a conclusion to this thesis. It summarizes the results from Chapter 4 with respect to the research objectives. This chapter includes recommendations to improve the quality of this study for future studies. This chapter proposes several recommendations, which might be useful in design and optimal sampling strategy for future monitoring purposes, as well as further actions to conserve and protect these freshwater fish species and the river quality.

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