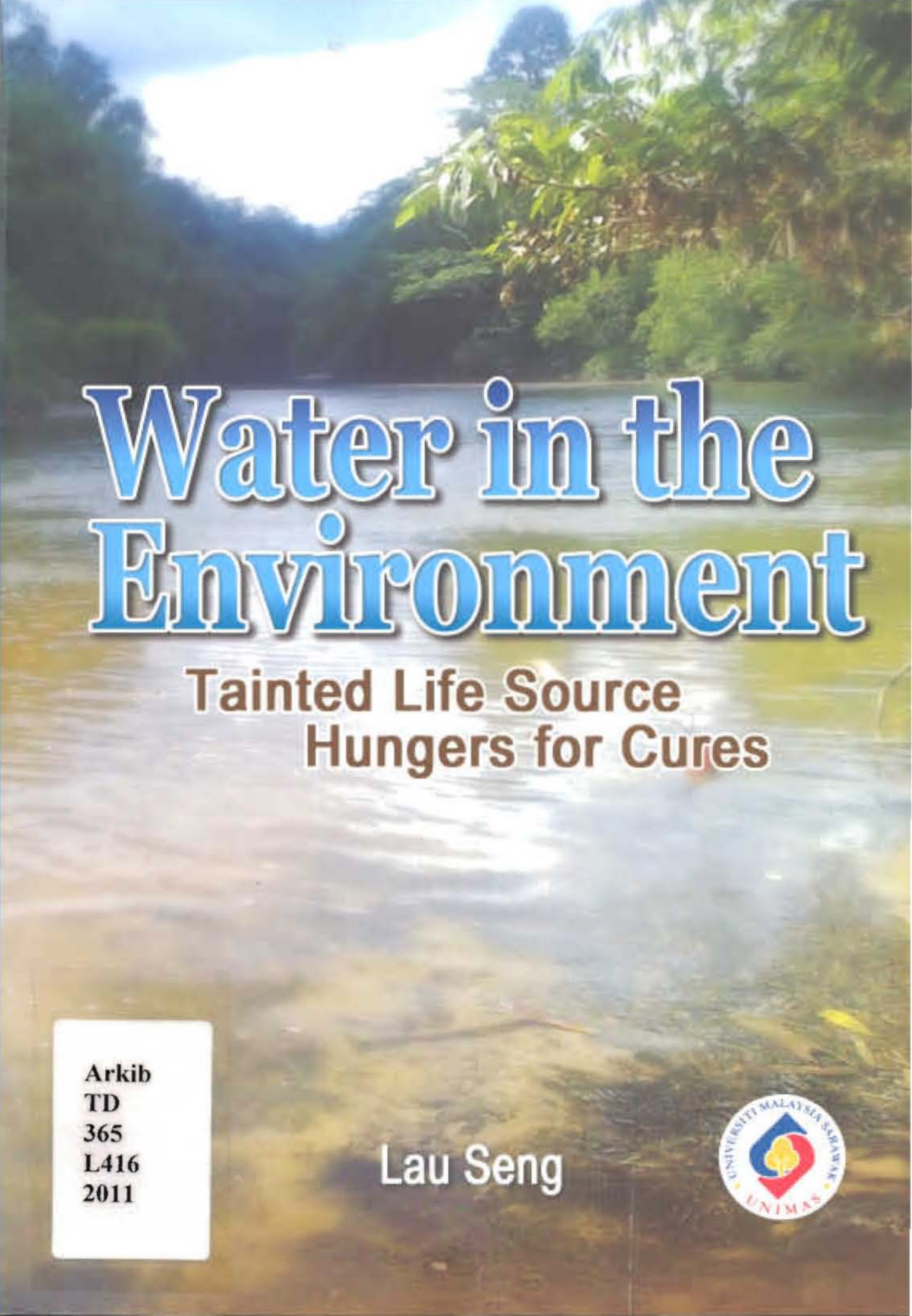

Water in the Environment

Tainted Life Source Hungers for Cures

Lau Seng

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Water in the Environment

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Lau Seng

Universiti Malaysia Sarawak,
2011

PREFACE

This booklet is a complete roundup to the inaugural lecture for the appointment of professorship at Universiti Malaysia Sarawak. The contents are based on papers presented in seminars and conferenees, published in proceedings and journals, and reports submitted for consultancy projects. The content deals with the basic water chemistry, followed by the analytical methodologies for the aquatic environment assessments, wastewater treatment technologies. and approaches and water resources management system.

The studies were conduct on surface water in Sarawak. Chapter 2 deals with the basic water chemistry and the common water quality parameters that were measured for the calculation of the Malaysian Water Quality Index (WQI-DOE). Chapter 3 summarises the water quality studies that have been conducted in several rivers and lakes in Sarawak to gauge the overall status of the water quality in Sarawak, while the methodologies developed for monitoring the aquatic environment are discussed in Chapter 4. Techniques applied in the biomonitoring of heavy metals in the freshwater environment. determination of the carrying capacity of an estuary and sediment distribution, and pollutants monitoring were discussed. Chapter 5 deals with wastewater treatment technology which include biofiltration, constructed wetland. and ecological sanitation system. Highlight on the management of water resources covers only the integrated water resource management with focus on Sg. Sarawak basin, and this is covered in Chapter 6. This book ends with the conclusions of our research on water chemistry, analytical methods, wastewater treatment, and water resource management in Chapter 7.

I hoped that the book will give readers an overall view of the water resources in Sarawak and provides a reference material for future studies in this area.

Lau Seng

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The research projects which were conducted during my employment at Universiti Malaysia Sarawak (UNIMAS) were mostly in collaborations with my students (BSc., MSc. and Ph. D.), my colleagues and counterparts at other institutions, and reputable professionals. I wish to express my sincere gratitude for all their hard works and scholarly contributions. I am deeply indebted to all these creative, hard working, and esteemed researchers who have assisted me during the course of my research works, for without them, the outputs which are evidenced here would not have materialised. I would like to thank UNIMAS for giving me the opportunity to realise my full potential in research; and for providing me with the necessary supports, in terms of research grants, research facilities (equipments and laboratories), and the motivation. In the course of my work, I have travelled the length and breadth of Sarawak, spending numerous nights by the river banks, in the jungle. and in various longhouses. I would also like to thank my fellow researchers and field assistants who have accompanied me during these trips and the people of Sarawak who have given us their cooperation and the accommodation during our work.

Most importantly I would like to thank my wife, Prof. Dr. Kasing Apun for her patience and encouragement throughout my work; and my children, Reening and Suet Ling, who being the techno-savvy Generation Y, have always been handy in the preparation of my presentation slides. To my mother, Madam Yee Choy Fong, words cannot describe my gratitude for all the things she had done for me and my family.

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1 INTRODUCTION

Water is an integral part of human civilisation. It is distributed rather unevenly across the world and regions where water is insufficient are called deserts while areas where there is an over supply are call wetlands. Areas that store water are called water bodies.

The importance of water in sustaining lives on earth needs no emphasis. However, the fate that water went through after they have performed their sacred duties are mostly unknown. This, either due to sheer ignorance or the ill-informed assumption that water is in abundance, and therefore, will always be there no matter what happens. Hence, not much attention is given to the source of life (Lau et al., 2005a; 2005b).

The above attitude is particularly true for the State of Sarawak as it receives an annual rainfall of more than 4,500 mm. With such high rainfall value, it seems unbelievable or unthinkable for the State to have water shortages. But on the contrary, incidences of water shortage are common, particularly in the remote and isolated areas unreachable by the main water distribution pipes. The shortage in water supply is strongly believed to be due to two main factors: firstly, weather or climatic conditions that provide a long period of drought; and secondly, pollution factors that render the water no longer fit for human consumptions.

The first factor (climatic pattern) is easily verified as the Department of Irrigations and Drainage (DID) maintain weather stations throughout the country. According to the current climatic pattern, the rainfall pattern in Sarawak predicts dry spell in the month of March and between June and August where the monthly rainfalls for those months are less than 300 mm. The second factor, water pollution, is not so easy to verify. It requires the monitoring and analyses of water samples. There are constrains within the environmental agencies to carry out these requirements and these are the limited man power, finance, and technical know-how.

Sadly, while the relevant agencies continued to be plagued by those constraints, the environmental health status of most water bodies in the developing countries continue to suffer unsustainable exploitations and mistreatments. The number of polluted rivers, lakes, estuaries, and coastal waters are increasing. The degradations of the water bodies reflect the overall environmental degradation In most cases, environmental degradations seem to be closely linked to economic development (Lau & Pereira, 1998), and some groups prefer to believe that the environmental degradations are necessary trade-offs in our pursuit of monetary gains and economic prosperities. Unfortunately, it appears that such misjudge ideology has been widely accepted as true; hence, no public protest has been mounted on the continual degradation of our environment, particularly our water bodies. The trade-off excuse, however, is unjustifiable, and was put forward mainly to justify the unquenchable materialistic desire of some groups of individuals that have, in their pursuit of monetary gain, neglected their responsibility to protect the environment. But the fact is, through sustainable development concept and environmental best management practices, economic development and environmental health can co-exist and complement each other (Lau, 2009). The need for sustainable development was the main agenda of the Earth Summit in 1992 and to achieve its goals, we need to have strong scientific knowledge about the environmental processes.

Water component or the hydrosphere serves as a link between all the other environmental components, namely, the atmosphere, lithosphere and the biosphere. Water bodies are the trapping pool to all forms of pollutants. By deciphering the pathways by which pollutants disperse through our water system, we will gain a useful insight to the state of our environment. Therefore, a thorough chemical analysis of the water in environment is an important procedure in the scientific investigations of our water system (Lau, 2010).

All man-made pollutants are chemically toxic to living things. The presence of pollutants in the water system will definitely affect all aquatic organisms though the degree varies between types of pollutants. The effects may range from slight irritation to fatal, depending on the toxicity of the pollutants.

Some pollutants do not directly exert harmful effect on living organisms but may cause secondary effect which may ultimately lead to fatality. The most common example of this secondary effect is in organic pollutants which eventually find their way into the water system. Pollution of this nature may result in the destruction of living organism, such as fishes, in the affected lakes. While the pollutants may not be responsible for the fatalities, its effects on the lake ecosystem will. In this case, the excessive amount of pollutants in the water systems provides nutrients that promote algal blooms. The blooming alga will not only consume all the oxygen in the lake but it also blocks sunlight that is needed by submerged aquatic plants to initiate photosynthesis. Hence, the visible consequences would be the death of a massive number of fishes, not from the pollutant itself, but from imminent suffocation due to the lack of oxygen in the water. Most of the acute effects of pollutants, such as the aforementioned, are easily visible. No doubt, these incidences attract great public interest and create media impacts. Therefore, attentions are given quite immediately and situarions restored, at least to the eyes of the media and the public. But without proper planning and strategy in place, similar incidences may recur in the future.

The science of environmeutal pollution has recently receive much attention for rhe simple fact that it can explain the occurrences of pollutions, provide recommendations on treatment and management systems, and make forecast of future environmental status. The main objective of this text is to provide some scientific observations, analyses, treatment technologies, and management systems for the water resources in Sarawak. It will delve into four main topics, which are:

i) the status of the quality of water resources in Sarawak,
ii) the development of alternative analytical procedures in environmental analyses,
iii) water and wastewater treatment technologies, and
iv) water resources management in Sarawak.

2 SELECTED WATER QUALITY PARAMETERS

The quality of surface water in Malaysia is measured by the Water Quality Index (WQI) set by the Department of Environment, Malaysia. The WQI is calculated from six water quality parameters: pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Ammoniacal Nitrogen (NH_3-N). The significance of each parameter is described below (Lau, 1992; Lau & Murtedza, 2000).

DEGREE OF ALKALINITY OR ACIDITY (pH)

This parameter measures the concentration of hydrogen ions in water. It represents the negative value of the logarithm of the concentration of hydrogen ions (H^+). Mathematically it is expressed as:

$$pH = -\log[H^+]$$

Based on the dissociation constant of water, $K_w = [H^+][OH^-] = 14$; at neutral condition, the pH is 7. All pH that are less than 7 denotes acidic environment, while pH of more than 7 denotes alkaline. In natural conditions, the pH of water is between 6 and 8. Slight acidic water is mainly due to dissolved carbon dioxide from the atmosphere, while a slight alkaline condition is mainly due to the presence of calcium carbonate (limestone). In some exceptional conditions, such as in peat areas, water pH can go as low as 4 due to the release of humic acids from the decaying woody material in the peat (Lau et al., 1994).

When the pH of a water body is very acidic (pH <4) or very alkaline (pH > 9), they normally indicate the presence of industrial discharges or acid mine discharges. Under both acidic or alkaline conditions, aquatic life will be adversely affected and may eventually lead to their destruction.

DISSOLVED OXYGEN (DO)

DO is extremely important in supporting aquatic life. Atmospheric oxygen dissolved in surface water so that aerobic aquatic organism could breathe in the oxygen molecules: some through their gills, while others through diffusion across the skin. The solubility of oxygen in water is 8.4 mg/L at 20 °C. This solubility is somewhat inversely proportional to temperature. At higher temperature, such as the temperature of tropical surface water (28 – 30 °C), the solubility of oxygen is approximately 7 – 7.5 mg/L. The solubility of oxygen is also dependent on its diffusion rate, and tbis can be enhanced by turbulence. Therefore, a swift flowing river will have higher DO due to the continuous mixing of oxygen and water, while a stagnant pond will have lower DO. Oxygen producing aquatic plants (such as algae) will increase the DO of the water body during the day, when they photosynthesise, but will consume the DO at night during their respiration. Other oxygen consuming substances include organic matters which originate from decaying vegetative debris, food wastes, and sewages (Lau et al., 2000a).

BIOCHEMICAL OXYGEN DEMAND (BOD)

When organic matters, either dissolved or suspended, are present in water bodies, natural existing microorganisms will consume them through a biochemical process. This process is called decomposition or biodegradation. In most natural processes, the biodegradation occur in the presence of oxygen by aerobic microorganisms. When microorganisms break down the organic matters, oxygen is consumed and carbon dioxide is released. The amount of oxygen consumed in this process is known as BOD. Therefore, this is an indirect measure of the amount of organic matter in the water body. BOD is measured over a five (5) day period at 20°C, and it refers to the amount of oxygen consumed per liter of the water sample. In natural conditions, BOD comes from decaying vegetative debris and the values are less than 2 mg/L.

The main sources of BOD are from animal waste, agricultural wastes (palm oil mill effluent), sewage, food wastes, and abattoirs wastes (Lau, 2002a). The significance of this parameter is that, when BOD is high, DO in the water sample will be depleted and this will eventually suffocate all aquatic life.

CHEMICAL OXYGEN DEMAND (COD)

This parameter is similar to that of BOD. However, COD measures the amount of organic matters that are chemically oxidisable. This measurement can be done by refluxing water sample with chromic acid as the oxidant, at 120 °C for two hours. COD is useful in monitoring industrial discharges, where some of the organic wastes are not easily degraded by microorganisms.

In natural unpolluted conditions, COD is normally less than 20 mg/L. The presence of chloride (Cl^-) and some metal ions such as iron (II), (Fe^{2+}), can interfere with the measurement of COD (Lau & Murtedza, 2000). Therefore, in samples with chloride or iron ions, additional steps are required to first remove the interfering ions before measurement of COD is conducted.

TOTAL SUSPENDED SOLIDS (TSS)

In regions where the mean annual rainfall is more than 3,500 mm, soil erosion by surface runoff is rampant. The extent of soil erosion is amplified when some land use activities (deforestation, large scale plantation, road constructions, and mining) remove the ground covers, and thus, exposing the soil (Lau et al., 2005c). Surface runoffs will then carry with them the loose soil particles (sand, silt and clay) as they make their way into the rivers. The eventual effect is a river water that appears turbid (yellowish and muddy) and no longer transparent. By measuring the amount of suspended soil particles in the water, it is possible to estimate the degree of soil erosion from the catchment. Suspended solids are found to be an effective remover of dissolved heavy metals (Lau & Chung, 1997). Finer particles have a higher capacity and efficiency in adsorbing cations. Also, the adsorption of heavy metals by suspended solids is effective at pH as low as 4.

In terms of water quality, the presence of high amount of suspended solids will increase turbidity, preventing sunlight from penetrating deeper into a water body to support photosynthesis of aquatic plant. When the suspended solids settle into the river bed, it will cover and bury most of the benthic organisms, and destroy the spawning grounds of fish and fish eggs. Smaller particles in the water body will clog the gills of fishes and suffocate them. Therefore, the TSS value of a water body indicates the degree of soil erosion for that catchment, as well as the health of the aquatic habitats in the water body.

AMMONIACAL NITROGEN (NH_3-N)

All organic matters that originate from living organisms contain protein. The backbone of protein are amino acids that contain nitrogen. The first stage of decomposition involves the breakdown of amino acids by bacteria; a process that releases ammonia (NH_3). As the ammonia molecules build up, *nitrosomonas* bacteria will convert them to nitrite (NO_2^-), which will then be converted to the stable nitrate (NO_3^-) by the *nitrobacter* bacteria. The entire process of decomposing protein until it becomes nitrate will take about 30 to 50 days.

In the natural environment, the sources of NH_3 are from vegetative debris and animal wastes and carcasses. The normal concentration of NH_3-N in natural water is less than 0.3 mg/L (Lau et al., 2005a; Lau et al., 2006b). When anthropogenic influences are present, the sources of NH_3-N are from untreated sewage discharges, animal wastes discharges, and food and kitchen wastes. The detection of higher than 0.3 mg/L of NH_3-N in a water body indicates the presence of freshly (within one week) discharged organic wastes (sewage, fresh aquaculture wastes, food wastes, etc).

OTHER COMMONLY MEASURED PARAMETERS

Other commonly measured parameters include temperature, which is for determining the potential of thermal pollution from industrial cooling water discharges. Electrical conductivity may also be measured to determine the amount of dissolved ions. Such ions mostly come from inorganic materials (geologic materials – rocks, and minerals). Also, industrial wastes, which normally containing metal ions, can increase the electrical conductivity of water. Electrical conductivity is also associated with the Total Dissolved Solids and salinity.

Measurements of nutrients, such as nitrates (NO_3^-) and phosphates (PO_4^{3-}), are also made to detect the release of fertilisers from agriculture fields and estimate the potential of eutrophication of the water body. On the other hand, measurements of coliform bacteria are indicative parameter for sewage contamination, in particular the measurement of the *E. coli* bacteria or the feacal coliform.

In addition, heavy metals such as lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni) and zinc (Zn) are sometime measured to trace the discharges from electronic and plating industries, mine tailings, and batteries manufacturing. Most of these heavy metals are very toxic to human health. Also, determination of pesticides in water bodies is done solely for investigative and compliance purposes and is targeted at the agriculture sector (plantations). The main concern is leaching of pesticides from farms into rivers. Pesticides are commonly grouped under the organochlorine (OC) and the organophosphorus (OP) group; and the analytical methods for pesticides determination are mostly very labourious and time consuming (Lau et al., 2005d; Chai & Lau, 2003a; 2003b).

3 THE STATUS OF WATER RESOURCES IN SARAWAK

Sarawak with its vast land area and high annual rainfall is undoubtedly the state with the largest water resources and reserves. Almost all the water supply in Sarawak is abstracted from surface water; except in Miri, where groundwater is also abstracted to supplement surface water. Due to the heavy dependence on surface water, and the constant changes in the landscape of the state, the usability of surface water has been greatly affected. Our evaluation of the water quality in various rivers in Sarawak has helped to take stock of the cleanliness status of the rivers in Sarawak. Those investigations were conducted from 1993 to 2010.

SAMUNSAM WILDLIFE SANCTUARY

At the Western tip of Sarawak lays the Samunsam Wildlife Sanctuary. The sanctuary covers about 61 km^2 of Gunung Pueh Forest Reserve and stretches from the Indonesian border in the west, to the state's coast in the east. The Samunsam River drains the catchment. The tributary of Samunsam River are Sg. Assam which is located outside the Sanctuary's boundary and Sg. Samunsam Buta Merah which is within the sanctuary. Part of the Samunsam catchment is not within the national park is, therefore, subjected to the impacts of other land uses.

An ecological study of Samunsam River Basin was conducted to assess the state of its ecosystem, including the water quality of the Samunsam River (Lau, *et al.*, 1994). In the study, a total of 16 sampling points were selected. The lower parts of the river were saline (about 1/3 of the river length). The remaining river stretches were quite low in their conductivity (23 – 58 µS/cm). The pH of the river also followed the pattern of the salinity. The lower reaches of the river, where the salinity was high, had pH between 6.62 and 7.20. The other reaches of the river had pH between 4.13 and 5.13. The river water was acidic and that was due to peat deposition in a large part of the catchment.

The water DO levels were consistently between 3.6 and 4.1 mg/L. The river was slow flowing and contained high amount of organic matters in the form of humic acids from the peat leachates. The organic matter, in the process of their oxidation, consumed oxygen in the water; and because of the river slow flow, the aeration rate was also slow. Hence, the DO measurements were well below the normal level of between 5 and 6 mg/L.

The study did not measure other water quality parameters. It was concluded that there was no pollution from anthropogenic activities within the Wildlife Sanctuary. However, some logging activities were observed at Gunung Pueh during the study and there was indication of soil erosion. This was visible from the muddy water at Sg. Assam which turned brownish as it flowed downstream where it mixed with peat water. Organic matter from the peat was responsible for consuming part of the dissolved oxygen.

The study also concluded that Samunsam River is acidic due to peat discharges. Vegetative debris from herbaceous plants, in addition to the presence of peat water, contributed to the organic matrer content in the water which increased oxygen demand and caused the DO level to be lower than average. The river was also slightly polluted by soil erosion.

THE KELABIT HIGHLAND (Lau, *et al.*, 1995a; 1997)

A multidisciplinary expedition was conducted at the Kelabit Highland of Bario from 10 – 20 April, 1995. Bario Asal is the main settlement of the Kelabit. It is located at the plateau; about 1,200 m a.s.l with an annual rainfall of 2,300 mm. The mean daily temperature of this area falls between 19 and 22 °C. The Kelabit Highland Plateau forms the uppermost catchment of Baram River Basin. The Plateau is drained by two main rivers: Pa' Marario and its tributaries, Arul Dalan, Pa' Lap and Pa' Ramapoh; and Pa' Ukat. Both these rivers and their tributaries drain into Sg. Dappur which drains into Batang Baram.

During the expedition, water quality study was conducted on the Pa' Marario and its tributaries, and on Pa' Ukat. A sample was also taken from Sg. Dappur. Results of the measurements are shown in Table 3.1. The highland has a relatively cool temperature of about 20°C. The relatively low water temperature dissolved more oxygen and this is reflected in the DO measurements; all measurements were above 6.60 mg/L. Also, another factor that contributes to the high DO values is the swift flowing water in most of the rivers. The flow in the three rivers, Pa' Ukat, Pa' Puak, and Sg Dappur were less swift compared to Pa' Marario, Pa' Ramapoh, and Arul Dalan. There were substantial amount of dissolved ions in the water; all of the rivers gave relatively higher value in their electrical conductivity (82 - 133 µS/cm) compared to some of the tropical rivers in Sarawak where the conductivities were marginally lower (< 60 µS/cm).

The appearance of turbidity indicated the amount of suspended solids in the water. In the study, turbidity level can be divided into three groups, namely, clear, moderately turbid and highly turbid. The Pa' Ramapoh, Arul Dalan, and Pa' Puak had clear water. Pa' Marario and Pa' Ukat were moderately turbid; while Sg. Dappur was highly turbid. The main cause of turbidity was soil erosion and the associated land uses of timber harvesting and land clearing for agriculture. The turbidity values were further supported by the total suspended solids (TSS) measurements. The clear rivers, recorded TSS of less than 40 mg/L, while the moderate turbidity river had their TSS ranging between 40 mg/L to 96 mg/L. The highly turbid river recorded TSS value of 260 mg/L.

Table 3.1: Water quality measurements of the rivers at Kelabit Highland Plateau (Lau, *et al.*, 1995a)

Sampling Station	Pa' Marario	Pa' Ramapoh	Arul Dalan	Pa' Ukat	Pa' Puak	Sg. Dappur
pH	5.90	5.71	5.75	5.12	6.05	5.15
Cond. (µS/cm)	83	82	90	91	106	133
Turbidity (NTU)	65	27	25	69	10	240
DO (mg/L)	7.45	8.10	7.95	6.80	6.70	6.60
Temperature (°C)	20.2	20.2	20.2	20.3	21.0	20.2
NH_3-N (mg/L)	0.03	0.06	0.14	0.22	0.06	0.17
NO_3^- (mg/L)	0.11	0.06	0.10	0.09	0.10	0.11
PO_4^{3} (mg/L)	0.16	0.09	0.12	0.12	0.11	0.12
TSS (mg/L)	96	33	37	40	26	161
BOD (mg/L)	2.0	0.7	0.9	1.3	0.9	1.3

The nutrient levels in the rivers were relatively low with most of them at the natural level. The ammoniacal nitrogen (NH_3-N) measurement, which is a measure of the first step of protein decomposition, were from 0.03 to 0.22 mg/L. Pa' Ukat registered the highest level of NH_3-N and this could be due to sewage discharges from the longhouse. Sg Dappur recorded 0.17 mg/L of NH_3-N and the main source for this may have came from animal waste, particularly buffalos as there was buffalo ranch at the vicinity of Sg. Dappur sampling point. Phosphates (PO_4^{3-}) measurements were low and that indicated the use of minimal amount of mineral fertiliser in the agriculture practices at Bario.

The overall water quality of Bario catchment appeared to be relatively good, and could be grouped under Class II Rivers. The main pollutants were suspended solids which came from soil erosions due to land clearing and timber harvesting. The catchment was under threat as timber concessions have been given in areas within the Kelabit Highland Plateau. It was recommended that the Kelabit Highland be made a conservation area to conserve its uniqne natural heritage.

THE BATANG RAJANG (Ekran., 1995; Hashim & NEH, 2003)

In the early 1990s, the construction of one of the world largest dams (Bakun Dam) was proposed across Batang Balui, the upper reaches of Batang Rajang. An environmental impact assessment study was conducted and was led by the Centre of Technology Transfer and Consultancy, UNIMAS. That gave us the opportunity to conduct a background study and to determine the status of the water quality of Batang Rajang.

Water Quality Study

The study was conducted during the dry (July, 1994) and the wet (Nov. 1994) seasons (Ekran, 1995). The study was divided into two sections: the upstream and the downstream of the proposed dams. The results of the study are shown in Table 3.2 and are summarised in the following headings.

pH

The upstream of the Bakun Dam was generally neutral with pH ranging from 7.33 to 7.90 during the dry season. The pH decreased to between 6 and 6.93 during the early part of the rainy season (Nov. 1994). The recorded pH reflects the typical conditions of tropical fast flowing streams such as the Batang Balui. In the early stages of the rainy seasons, acid produced by the decaying vegetative debris in the forest floor is washed down into the river. That managed to decrease the pH reading by 1 unit which refers to a 10 times increase of hydrogen ions (H^{-}) in the water.

Conductivity

The water in Batang Balui and Sg. Murum (upstream of Bakun Dam) had low conductivity (< 50 µS/cm) during the dry season and were even lower in the rainy season (<25 µS/cm). The values indicated low dissolved solids.

Turbidity and Suspended Solids

Batang Balui and Sg. Murum at the upstream of the Bakun Dam were slightly turbid during the dry season: turbidity between 20 and 46 NTU; and TSS between 170 and 299 mg/L. Their tributaries, such as Sg Bahau, Sg. Linau, and Sg. Buko, were relatively clear with turbidity in the range of 3 to 11 NTU. However, the rivers were heavily laden with suspended solids during the rainy season. Our analyses showed that in November 1994, the turbidities were between 288 and 442 NTU and these correspond to TSS of between 460 and 1009 mg/L. The findings indicated that the catchment area has been heavily disturbed, mainly through logging activities (Lau & Murtedza, 2000). Downstream from the dam, Belaga to Sibu, turbidity remained consistently above 260 NTU but TSS measurements stayed between 583 and 763 mg/L during the rainy season. The reduction in the TSS but not turbidity was due to the deposition of coarser particles (such as sand) while the finer particles (that causes turbidity) remained suspended.

Dissolved Oxygen (DO)

The upstream region recorded DO values between 7 and 9 mg/L. That level was achievable due to the river swift flow and frequent formation of rapids. These provided natural mechanical aeration that gave the high DO level. As the river moved downstream, the flow became slower and fewer rapids formed. These translated into lower recorded DO values from Belaga to Sibu: between 5.4 and 5.9 mg/L. Nevertheless, the levels are still considered good and ideal for aquatic organisms (Lau & Murtedza, 2000).

Biochemical oxygen demand (BOD)

The BOD of the upstream was measured to be between 0.45 and 2.00 mg/L. The values indicated a good and normal water quality. The BOD for the downstream section, however, was slightly higher, between 1.2 and 2.3 mg/L. That could be due to the discharges of untreated sewage from settlements along the river from Belaga to Sibu.

Chemical oxygen demand (COD)

The COD is similar to BOD, except that COD is a chemically induced oxidation of organic matters in 2 hr. It also breaks down some non-biodegradable materials. The upstream values were between 2 and 19 mg/L during the dry season. During the wet season, the COD values increased to between 90 and 171 mg/L. The vegetative debris which was washed down by the surface runoffs was the main reason for the increase in COD. Downstream stretches of Batang Rajang recorded COD values between 20 and 40 mg/L, with Sibu and Kapit being on the high side which might be due to the numerous numbers of boats travelling and docking at these two towns, spilling some amount of fuels. However, the values recorded were not critical and was not considered polluting.

Nutrients (NH_3-N. NO_3^-, PO_4^{3-})

The nutrients levels in the river were low with most of the species below or barely