

## THE SURFACE WATER RESOURCE OF CROCKER RANGE PARK, SABAH

Murtedza Mohamed<sup>1</sup>, Lee Yook Heng<sup>2</sup> and Geri Gopir<sup>2</sup>

### ABSTRACT

*The protection of the forest cover in headwater areas is crucial for the sustainability of downstream water resources, both in terms of quantity and quality. The Crocker Range Park (CRP) in Sabah has been gazetted primarily for this reason. A study was carried out to establish the catchment characteristics and water quality status of 12 major streams draining the eastern and western slopes of CRP. Analyses of both primary data sets and data sourced from the ongoing monitoring programmes by government agencies indicated that streams on the eastern slopes of CRP were generally of excellent quality although to some extent tainted with carbonate mineral leachate. Further downstream, the water quality of these streams and those draining the western flood plains were found to deteriorate, primarily by anthropogenic inputs such as suspended solids and faecal coliforms. Computation results for water quality-based river classification showed that all the streams studied generally belonged to Class II.*

### INTRODUCTION

Preservation of headwater areas has been generally acknowledged as crucial for the sustainability of stream water quality and supplies. Conflicting land and water uses and disregard for the protection of water catchment have resulted in several major crisis nationwide (e.g. Lim 1995; Abdullah & Jusoh 1997; Ithnin 1998; Murtedza et al. 1999; Hamirdin & Nordin 2000). Earlier studies on rivers and streams in Sabah for instance clearly indicated that the majority of streams and rivers in the state were greatly affected by suspended solid loadings, and the pristine quality conditions prevailed only in the upper catchment areas (Murtedza et al. 1987; Murtedza 1987a, 1987b; Lee & Murtedza 1989; Murtedza 1990a, 1990b; Lee et al. 1993; Murtedza & Ti 1993; Geri et al. 1999).

The Crocker Range Park (CRP) in Sabah has been gazetted in 1984 primarily for the purpose of sustaining the supply of good quality water to approximately 200,000 population residing in the West Coast and Interior Districts of Sabah. The Park reserve is the headwater area for 12 major streams draining these two sub-regions (Figure 1). Some of the key features of these streams and the predominant forms of land and water uses within their respective sub-catchments are given in Table 1. It is evident that apart from supporting the montane forest and riverine ecology, activities such as aquaculture, rice cultivation, commercial plantations and hydropower generation are greatly dependent on the water resource of CRP.

The hydrological database of most streams in Sabah, including those in the vicinity of CRP, are well compiled and documented by the Drainage and Irrigation Department. Similarly, the water quality monitoring by the Department of Environment (DOE) has been an ongoing initiative for nearly two decades now, though the task is presently privatised to Alam Sekitar Malaysia Sdn

Bhd (ASMA). Another water quality monitoring programme of great importance in Sabah is the weekly sampling at the water treatment plants state-wide by the Water Department of Sabah. During the last few years, DOE has also commissioned several river classification studies, including that for the Sungai Pegalan-Padas (DOE 1999). Most of the water sampling locations chosen by DOE however, are located either along the main river stretch or on major tributaries, with only a few located in the immediate vicinity of the headwater areas.

*Table 1. Major streams originating from CRP and their sub-catchment features*

<b>Stream</b>	<b>Channel Feature and Estimated Discharge at Sampling Location</b>	<b>Principal Land Use within Sub-catchment</b>	<b>Main Water Use</b>
Streams in the West Coast	Streams drop steeply from the CRP, meanders along the coastal flood plain and flow into the South China Sea.	Forest vegetation (FV), wet paddy (WP), oil palm plantation (OP), rubber plantation (RP).	Municipal and village supplies, irrigation
Sungai Papar	35m width (W) and 3m depth (D); <i>ca.</i> 27m <sup>3</sup> /s; alluvial channel.	FV, WP	Municipal and village supplies, irrigation
Sungai Kimanis	15m W, 1.5m D; <i>ca.</i> 5m <sup>3</sup> /s; alluvial channel	FV, WP	Industrial and village supplies, irrigation
Sungai Bongawan	10m W, 1.5m D; <i>ca.</i> 2.2m <sup>3</sup> /s; alluvial channel	FV, WP, RP, OP	Village supplies and irrigation
Sungai Membakut	9m W, 1.2m D; <i>ca.</i> 1.2m <sup>3</sup> /s; alluvial channel	FV, WP, RP, OP	Village supplies and irrigation
<i>Streams in the Interior Districts</i>	All streams feed into Sungai Pegalan and Upper Padas. Discharge at lower Pegalan is <i>ca.</i> 500m <sup>3</sup> /s	FV, mixed small-holding highland crops (MC), WP, RP	Municipal/village supplies, irrigation, aquaculture, recreation and hydropower generation
Sungai Tandulu	7m W, 0.3m D; <i>ca.</i> 1.5m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Municipal and village supplies, aquaculture and irrigation
Sungai Tikolud	3m W, 0.3m D; <i>ca.</i> 1.2m <sup>3</sup> /s; rocky bed in a valley	FV, MC, WP,RP	Village supplies and irrigation
Sungai Apin-Apin	6m W, 0.4m D; <i>ca.</i> 3m <sup>3</sup> /s; rocky bed	FV,WP, RP	Village supplies, aquaculture and irrigation
Sungai Baiayo	20m W, 0.8m D; <i>ca.</i> 11m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Municipal, industrial and village supplies, recreation, irrigation
Sungai Liawan	7m W, 0.4m D; <i>ca.</i> 1.8m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Municipal and village supplies, irrigation
Sungai Pampang	5m W, 0.3m D; <i>ca.</i> 1.5m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Village supplies and irrigation
Sungai Masalog	8m W, 0.5m D; <i>ca.</i> 2m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Village supplies and irrigation
Sungai Melalap	5m W, 0.4m D; <i>ca.</i> 1.5m <sup>3</sup> /s; rocky bed	FV, MC, WP,RP	Village supplies, aquaculture, irrigation



Meteorological data were sourced from the Hydrology Division, Drainage & Irrigation Department, Sabah. Field samplings of water and surveys on the stream and catchment features were carried out in October 1999 during the Crocker '99 Scientific Expedition.

**Hydrological survey.** Channel geometrical characteristics of streams were profiled through direct measurement of the cross-section or by triangulation. Hand-held current meter was used to estimate the stream flow.

**Water and *in-situ* water quality data sampling.** Water samples and *in-situ* water quality data were collected twice (on consecutive days) from the 12 streams. The locations of sampling points are shown in Figure 1. Water samplings were carried out by wading at mid-depths in the middle of the streams. Samples were preserved according to the ISO5667/1 Guidance for Water Quality Sampling. *In-situ* water quality data samplings for non-conservative and non-preserved parameters (temperature, pH, dissolved oxygen, turbidity, and conductivity) were determined on-site using a Hydrolab® Surveyor MK-II.

**Water Analysis.** Non-conservative and preservable water quality parameters such as biochemical oxygen demand (BOD), nutrients, and coliforms were analysed within 8 hours at the field laboratory. Standard Methods (APHA, 1996) were used in the quantitative analyses of metals (Ca, Mg, Fe), nutrients (nitrate, ammonia, and phosphate) and total suspended solids. Except for mercury (Hg), toxic trace metals (As, Cd, Cr, Pb, Hg) were analysed by graphite furnace atomic absorption spectrophotometry (AAS, Perkin Elmer 3300). Hg was analysed using cold vapour AAS. Total coliform and *E. coli* counts were determined using the Paqualab filtration method.

**Stream Classification.** Water quality data for seven streams at eight DOE monitoring stations were selected for the purpose of stream classification (Table 2). For each station, approximately 3-5 sets of data per parameter were usually available for each year. The total number of data per water quality parameter for 8 years (1989-1997) for each station, except for Kambizaan, were close to 40. The data was first screened to remove the outliers, e.g. zeros, unusually large/small values for pH, dissolved oxygen or conductivity. After data screening, description statistics was used to obtain average, standard deviation, maximum and minimum values of a particular parameter within the 1989-1997 period.

Water Quality Indices (WQI) for each stream were then calculated according to the procedure adopted by the DOE (1993). This procedure used six water quality parameters, namely pH, dissolved oxygen (DO % saturation), total suspended solids (SS), ammonical nitrogen (AN), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The calculation of WQI was on a year to year basis for each station and the 90 percentile of each parameter was employed in the computation. From the 90 percentile, the water quality sub-index for each parameter in each year was first determined and this was then input for computing the WQI according to the following equation (DOE 1993) where the prefix SI stands for sub-indices:

$$\text{WQI} = 0.22\text{SIDO} + 0.19\text{SIBOD} + 0.16\text{SICOD} + 0.15\text{SIAN} + 0.16\text{SISS} + 0.12\text{SipH}$$

Table 2. Streams and locations of DOE water quality mentoring stations

Regional grouping	Stream	Location of Sampling Station	DOE Station Code
CRP and Interior Districts	Tandulu	On the eastern slope of Crocker Range (CR), 3.6km from CRP boundary, 220km from the sea.	5663612
	Baiayo	At Bunsit on the eastern slope of CR, 3.7km from the CRP boundary, 155km from the sea	5461616
	Liawan	On the eastern slope of CR, 2.2km from the CRP boundary, 145km from the sea	5361615
	Pengalan	At Pangsawangan, in the Tenom valley below the confluence of Padas-Pegalan, 75km from the sea. Average distance from CRP boundary: 60km	5158606
West Coast	Padas	At Beringin, near Beaufort on the main Sg. Padas 37km from the sea	5356601
	Padas	Near Beaufort on the main Sg. Padas 65km from the sea	5359614
	Membakut	At Limantok on the main Sg. Membakut, 24km from the CRP boundary and 42km from the sea	5458601
	Papar	At Kambizaan on the main Sg. Papar, 27km from the CRP boundary and 23km from the sea	5660604

Using the WQI values, the class of river was ascertained and the possible water use was established according to that adopted by the DOE (1993) (Table 3).

Table 3. River classification based on WQI Malaysia (DOE, 1993)

Class	WQI	Water use
I	92.6-100	Environmental conservation & protection, water supply and aquaculture of highly sensitive species
II	76.4-92.6	Water supply, aquaculture of sensitive species and recreation involving water-body contact
III	51.9-76.4	Water supply with extensive water treatment, aquaculture of tolerant species and livestock consumption
IV	30.5-51.9	Irrigation
V	0.0-30.5	Others uses not categorised in I-IV above

## RESULTS AND DISCUSSION

The present study compiled three water quality data sets: (i) data from the field samplings carried out during the CRP 99 expedition, (ii) a limited number but recently generated results of weekly analysis obtained from the Water Department of Sabah, and (iii) a long-term quarterly sampling results of the water quality monitoring programme provided by the DOE. The availability of these data sets suggested two possible assessment strategies:

- a short range assessment based on the two more recently generated data sets. This assessment would address the status of water quality at parametric level as measured during 1998/99;

- a long range assessment based on 8-year stream water quality monitoring data provided by the DOE. The data sets in this case would be adequate for the purpose of classifying each of the streams studied, thus providing an indication of the long term water quality status and the appropriate category of water use of these streams

Table 4. Water quality data obtained from duplicate sampling and analysis of stream water in the vicinity of CRP

	Temp	pH	DO (mg/L)	Cond (mS/cm)	Turb (NTU)	TSS (mg/L)	Nitrate (mg/L)	NH <sub>4</sub> (mg/L)	PO <sub>4</sub> (mg/L)	Faecal coli (cfu/100mL)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)
<i>Streams in the Interior Districts</i>													
Tandulu	20.0	8.2	8.8	87	59	11	0.39	0.05	0.01	30	5.48	2.08	0.04
Tikolod	21.4	8.0	8.1	113	54	10	0.35	0.05	0.02	12	1.96	3.94	0.11
Apin-Apin	25.5	8.1	8.2	99	134	66	0.70	0.62	0.04	272	4.56	2.53	0.20
Baiayo	25.3	8.6	8.2	95	62	17	0.44	0.13	0.03	328	2.58	2.81	0.06
Liawan	26.0	8.3	8.3	123	32	5	0.18	0.05	0.02	59	5.88	2.92	0.01
Pampang	27.3	8.4	7.8	111	38	14	0.40	0.03	0.03	307	5.02	2.69	0.04
Masalog	31.2	8.5	7.7	191	36	10	na	na	na	204	na	na	na
Melalap	25.1	8.3	8.6	68	58	16	0.70	0.70	0.04	270	0.23	1.96	0.15
<i>Streams in the West Districts</i>													
Membakut	25.8	6.7	6.2	26	<500	584	1.01	bd	0.02	2729	0.01	0.45	0.09
Bongawan	24.9	6.6	7.1	26	382	188	0.13	0.10	0.02	3754	0.01	0.53	0.23
Kimanis	25.0	6.8	7.3	41	320	118	0.44	0.05	0.16	1802	0.03	0.96	0.17
Papar	24.3	7.0	7.2	33	352	48	bd	0.20	0.11	2283	0.07	0.87	0.19

### Short range water quality assessment

Tables 4 and 5 presented water quality data obtained during the present study while Table 6 summarised the data provided by the Water Department based on weekly sampling and analyses carried out during 1998/99. Close examination of these two data sets showed a generally comparable range of values for most parameters. Some of the interesting water quality features characterising the streams studied are given in Table 7.

Streams running down from the eastern (interior) slopes of CRP generally showed a higher level of alkalinity and water hardness. These characteristics were probably attributable to the natural leaching of bedrock containing carbonate minerals. Limestone lenses were known to occur at several locations within the CRP boundary, with a major deposit occurring in the Baiayo sub-catchment at Lian (Tongkul, *pers. comm.*). The elevated level of conductivity appeared to also correlate well with the high contents of Ca and Mg.

Table 5. The average content of toxic metals in the rivers from the CRP

Station	As ( $\mu\text{g}/\text{l}$ )	Pb ( $\mu\text{g}/\text{l}$ )	Cr ( $\mu\text{g}/\text{l}$ )	Hg ( $\mu\text{g}/\text{l}$ )	Cd( $\mu\text{g}/\text{l}$ )
Tandulu	1.86	3.0	5.00	0.05	bd
Tikolud	bd	bd	2.50	bd	1.30
Baiayo	5.89	bd	6.25	bd	bd
Liawan	1.64	2.0	2.50	2.88	bd
Pampang	5.95	bd	4.35	0.09	bd
Masalog	5.12	2.0	9.25	0.07	bd
Melalap	7.35	bd	2.10	0.03	0.12

bd-below detection limit; na-not analysed

Detection limits: As=  $1\mu\text{g}/\text{l}$ ; Cd=  $0.1\mu\text{g}/\text{l}$ ; Cr= $2\mu\text{g}/\text{l}$ ; Pb= $1\mu\text{g}/\text{l}$ ; Hg=  $0.009\mu\text{g}/\text{l}$

Table 6. Water quality data based on weekly sampling, obtained from the Water Department

	Papar		Membakut		Bingkor		Keningau		Tambunan	
	(Sg. Papar 1/99-6/99)		(Sg. Membakut 1/99-5/99)		(Sg. Baiayo 2/99-5/99)		(Sg. Liawan 6/98-5/99)		(Sg.Tandulu 6/98-4/99)	
	Mean (n=8)	SD	Mean (n=5)	SD	Mean (n=6)	SD	Mean (n=17)	SD	Mean (n=16)	SD
Turbidity (NTU)	55	37	283	201	31	42	8	7	14	8
Colour (Hazen)	139	111	580	335	73	81	24	11	40	16
PH	6.9	0.1	6.5	0.1	7.4	0.3	7.7	0.2	8	0.1
Conductivity ( $\mu\text{S}/\text{cm}$ )	49	8	42	6	90	13	140	27	98	19
Dissolved Oxygen ( $\text{mg}/\text{L}$ )	7.5	0.9	7.5	0.8	6.7	0.8	6.8	0.7	6.8	0.7
Total hardness ( $\text{mg}/\text{L}$ )	22	6	19	7	40	6	66	11	45	10
Total alkalinity ( $\text{mg}/\text{L}$ )	23	5	17	4	41	4	69	14	47	9
Ammoniacal-N ( $\text{mg}/\text{L}$ )	0.09	0.12	0.07	0.06	0.06	0.04	0.06	0.03	0.06	0.05
Nitrate-N ( $\text{mg}/\text{L}$ )	0.06	0.05	0.09	0.10	0.06	0.06	0.05	0.07	0.05	0.06
Fe ( $\text{mg}/\text{L}$ )	0.05	0.12	4.10	3.34	0.27	0.38	0.11	0.08	0.17	0.12
Mn ( $\text{mg}/\text{L}$ )	0.09	0.04	0.22	0.19	0.08	0.07	0.03	0.02	0.04	0.03
Al ( $\text{mg}/\text{L}$ )	0.07	0.11	0.07	0.03	0.03	0.03	0.05	0.04	0.05	0.07
Chloride ( $\text{mg}/\text{L}$ )	3	1	3	1	2	1	2	1	2	1
Sulphate ( $\text{mg}/\text{L}$ )	3	4	4	3	6	3	4	3	2	1

The lower readings of Ca and Mg measured for the streams in the west coast were probably attributable to (i) the absence of significant quantity of carbonate minerals along the western slopes of CRP, and/or (ii) the difference in dilution factor resulting from the difference in the rainfall distribution for these two regions. It has been a well documented trend that the West Coast Region of Sabah received significantly more rainfall compared to the Interior Districts.

Thomas et al. (1976) reported a mean annual rainfall of 2,500-4,000mm for areas west of the Crocker Range, whereas areas east of this range recorded annual rainfalls of only between 1,500-2000mm. A long term monthly rainfall pattern for Beaufort and Papar in the West Coast and Tambunan, Apin-Apin and Keningau in the Interior Districts is shown in Figure 2.

The generally high level of TSS of the streams in the West Coast could be directly associated with the on-going land conversion in areas immediately below the western slopes of CRP. These included timber harvesting activities in the upper reaches of Sungai Membakut, and oil palm plantation in the middle and upper catchments of Sungai Bongawan and Sungai Kimanis.

Table 7. Summary of characteristic features and differences between the streams draining the eastern and western slopes of CRP

Parameter	Streams in the Interior Districts	Streams in the West Coast
pH	Alkaline (8.0 and above)	About neutral (6.6-7.0)
Conductivity	Relatively high (68-191µS/cm)	26-41µS/cm, within the normal range
Ca and Mg	Several folds higher than levels measured for streams in the West Coast	Normal range for 'soft water' streams
Suspended solids (TSS)	Except for Apin-Apin, TSS readings were low (<20mg/L)	In most instances TSS levels were above 50mg/L; highest reading was 584mg/L.
Faecal coliform	Generally under 300cfu/100mL	Approximately 10-fold higher than the level measured for streams in the Interior District

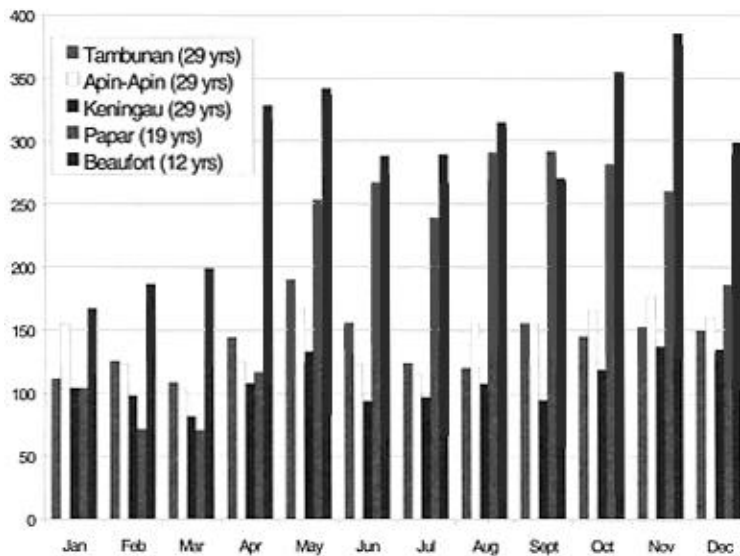


Figure 2. The rainfall distribution pattern for selected localities in the Interior and West Coast regions of Sabah.

As for the coliform counts, the elevated readings of faecal coliforms for the streams in the west coast was expected because the selected sampling points, the best accessible locations in this

area, were in the vicinity of riverbank settlements. These settlements were not equipped with proper sewerage/toilet facilities, thus those living along the streams would resort to building toilets on river banks or on rafts.

The concentrations of toxic metals such as As, Cd, Cr, Pb and Hg were very low and in the ppb range. Also, there was no obvious pattern of distribution of these metals in the river system, probably due to the absence of significant source of input.

### **Long range water quality assessment**

The 1989-1997 water quality data for the streams listed in Table 2 were analysed for the purpose of elucidating the changes in water quality status and relating them to the role of the CRP in conservation of water resources. The Tandulu, Baiayo and Liawan rivers were monitored by DOE at their sources close to CRP boundary. The pristine condition of these streams was thus considered as 'protected' by the forest cover of the Crocker Range.

The average values of various water quality parameters over an 8-year period showed that most rivers had satisfactory dissolved oxygen contents (> 80% saturation) and near neutral pH (6.7-7.6) with conductivity values generally not exceeding 100 $\mu$ S/cm, which was typical of Sabah's rivers. However, differences in values were rather significant between localities with regard to other water quality parameters. For example, marked differences were observed for total suspended solids, ammoniacal-nitrogen and COD where streams closer to the CRP boundary (especially Liawan and Baiayo) showed significantly lower values for these parameters compared to other streams. In general, based on the water quality parameters selected, the streams closer to the Park boundary showed good water quality throughout the eight years period.

The results of WQI computation (Table 8) indicated that these streams generally belonged to the Class II stream category most of the times although for certain years, some of these streams deteriorated to Class III stream category. Class I stream status was however occasionally attained by the Liawan and Baiayo located close to the CRP boundary. Thus, in terms of changes in WQI over the 1989-1997 period, the Padas and Pegalan river system seemed to be highly variable while those located close to the CRP boundary demonstrated a more stable water quality condition.

The variability of the WQIs could be explained by examining the water quality sub-indices of each of the water quality parameters contributing to the overall WQI. The sub-indices for DO, pH, ammoniacal-N and BOD were found to be generally high (>90) and showed little variability for most monitoring stations. This reflected an insignificant loading of readily biodegradable organic pollutants into these well aerated streams. As for SS however, a wide variation was noted in their sub-indices throughout the 1989-1997, especially for the Padas-Pegalan river where land use disturbances within the sub-catchment were generally more prevalent.

Linear regression of WQI data with sub-indices for COD or SS confirmed that good positive linear relationship existed between these sub-indices and WQIs. Except for the Papar River, other rivers demonstrated  $R^2$  value of 0.5-0.8, indicative of a strong relationship. Thus, the variability of the WQIs at each of the rivers was attributed to the wide variation in the COD and SS of the river water. The former was probably attributable to the constant inputs of natural

leachate from the non-readily degradable freshly humified forest vegetation, while the latter could probably be associated with both land use conversion and the natural erosion of stream channels. It has been earlier established that the alluvial channel of the lower Pegalan was extremely susceptible to channel erosion (Murtedza et al. 1987).

## CONCLUSION

Examination of the water quality database for streams in the vicinity of the CRP clearly indicated marked differences in the level of certain parameters between the streams in the west coast and those in the Interior Districts. It was most likely that the elevated levels of pH, conductivity, and Ca and Mg contents detected for streams on the 'interior' slopes of CRP resulted primarily from the natural leaching of carbonate minerals. The higher degree of stream siltation of the streams in the West Coast on the other hand was of anthropogenic origin, i.e. resulting from disturbances taking place in the catchment between the CRP boundary and the locations where water was sampled. In the absence of major contributing sources, the concentrations of toxic metals such as As, Cd, Cr, Pb and Hg in all the streams studied were, as expected, low i.e. in the ppb range.

*Table 8. The water quality index (WQI) and class of river for the streams in the vicinity of Crocker Range Park for the period 1989-1997*

Year	CRP-Tandulu		Baiyayo-Bunsit		CRP-Liawan		Pegalan-P'wangan	
1989	80	II	79	II	id	-	78	II
1990	86	II	89	II	88	II	89	II
1991	85	II	87	II	87	II	85	II
1992	83	II	90	II	86	II	83	II
1993	91	II	86	II	75	III	79	II
1994	id	-	92	II	88	II	84	II
1995	53	III	96	I	94	I	84	II
1996	91	II	87	II	81	II	88	II
1997	89	II	86	II	87	II	92	II
Aggr. <sup>1</sup>		II		II		III		III

	Padas-Beaufort		Padas-Beringin		Sg. Membakut		Papar-Kambizaan	
1989	69	III	90	II	86	II	id	-
1990	id	-	83	II	91	II	id	-
1991	82	II	87	II	82	II	id	-
1992	83	II	81	II	85	II	id	-
1993	id		84	II	92	II	86	II
1994	90	II	75	III	id	-	74	III
1995	id	-	90	II	89	II	85	II
1996	85	II	88	II	90	II	81	II
1997	85	II	82	II	81	II	82	II

Notes: <sup>1</sup>Aggregate classification based on hydrology-geomorphic-landuse, present beneficial use, water quality and aquatic ecology as reported in the Padas river classification study (DOE 1999).

id — insufficient dataset.

A long range assessment of the water quality database of the streams surrounding the CRP showed that the rivers situated close to the Park area demonstrated good water quality, mainly of Class II status and occasionally improved to Class I. However, the classification of river stretches farther away from the CRP boundary varied and occasionally deteriorated to Class III i.e. suitable for use as the source for drinking water supply only after extensive treatment. The high variability of the WQI for most rivers in the CRP vicinity was attributed to the wide variation in both SS and COD contents of the water. This finding should again supported the initiative of preserving areas upstream of drinking water sources.

### ACKNOWLEDGEMENT

The authors thank UNIMAS for the short-term research grant no. 179/99(33), Sabah Parks for the logistic support, the DOE (Sabah & F. T. Labuan), the Water Department and the Water Resource Management Division (DID) Sabah for providing the secondary data required for this study, and P. H. Lo, Rajuna Tahir and Amin Mangi for their technical supports.

### REFERENCES

**Abdullah K. and J. Jusoh.**

(1997). An appraisal of Malaysia's water resources: Problems and prospects. In *State of the Malaysian Environment*. Consumer Assoc. Penang.

**DOE** (Department of Environment)

(1993). Development of Water Quality Criteria and Standards — Phase IV (River Classification). Final Report, Vol. I — Executive Summary.

(1999). Projek Kawalan Pencemaran Air: Kajian Mengkelaskan Sungai-sungai di Malaysia. Vol. 8: Sungai Padas. Final Draft Report submitted by Unit Perundangan, Universiti Malaya.

**Geri G., Y.H. Lee and A. Engku Nor.**

(1999). A preliminary interpretation of water quality data for Papar River, Sabah using correspondence analysis. Paper presented in Malaysian Science and Technology Congress '99. 8pp.

**Hamirdin I. and S. Nordin.**

(2000). Effects of landuse on water quality in the Linggi river basin:

Prospects of sustainable land management. Intern. Symp. on Sustainable Land Management: Paradigms for the New Mellenium. Malaysian Society of Soil Science Publication. Kuala Lumpur.

**Ithnin H.**

(1998). An analysis of the 1998 water crisis in the Kelang Valley, Malaysia. Proc. V Intern. Conf. SEA Geogr. Assoc. Singapore.



**Lee Y.H., P. Jayaranjini, S.H. Teoh and G.L. Tan.**

(1993). The water quality of the Pegalan-Padas River: The Water Resource of Interior Sabah. Proceeding to the Tropical Natural Resource Symposium — Malaysian Natural Resources: Sustainability, Development and Strategies. Pelanduk Publ. 147-158.

**Lee Y. H. and Murtedza Mohamed.**

(1989). Effects of deforestation on the water quality of rivers and forest streams in the Tabin Wildlife Reserve. *Sumber* 5:147-152.

**Lim D.**

(1995). Land uses in Kundasang: Should the government intervene? *IDS (Sabah) Discussion Paper* No. 3.

**Murtedza Mohamed.**

(1987a). Water quality studies and water quality problems in Sabah. In Sham, S. (ed). *Environmental Conservation in Sabah — Issues and Strategies*. IDS Publication. Kota Kinabalu. pp. 41-54.

(1987b). Environmental impact of copper mining in Sabah. In Sham, S.(ed). *Environmental Conservation in Sabah — Issues and Strategies*. IDS Publication. Kota Kinabalu. pp. 55-63.

(1990a). Water Quality Scenario of Rivers in Sabah in Relation to Forest Operations. In *Intern. Conf Forest Biology and Conservation in Borneo* (Ghazally et al. eds). Yayasan Sabah Publ., Kota Kinabalu.

(1990b). Estimation of sediment yields of major watersheds in Sabah. *Proc. IHP/UPM/UNESCO Workshop on Watershed Development and Management for Asia Pacific*, 19-23 Feb 1990, K. Lumpur.

**Murtedza M, R. Stanforth, T.H. Tan and M.D. Kadderi.**

(1987). Determination of source and loading of solids in river tributaries. A case study. *Ilmu Alam* 16:101-117.

**Murtedza Mohamed and T.C. Ti.**

(1993). Managing ASEAN's forests. In *Environmental Management in ASEAN — Perspectives on Critical Regional Issues* (Seda, M. ed). Institute of Southeast Asian Studies (ISEAS) Publications, Singapore.

**Murtedza M., L. Seng, L.P. Ling, L.Y. Howe, N. Bessaih and K.A.A. Rahim.**

(1999). Potential Land and Water Use Conflict: A Case Study of the Bakong Watershed in Sarawak, Malaysia. *Proc. ICRAF Workshop Env. Services & Land Use Change: Bridging the Gap between Policy & Research in SEA*. International Centre for Research in Agroforestry (ICRAF). Chiang Mai.

**Thomas P., F.K.C. Lo and Ad. Hepburn.**

(1976). The land capability classification of Sabah. Vol. 4. The Interior Residency and Labuan. *Land Resource Study* 25. Land and Survey Division, Ministry of Overseas Development.

- 
- <sup>1</sup> Centre for Technology Transfer & Consultancy, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak.
  - <sup>2</sup> Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor.