August 2008

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ABSTRACT

The region of Monteverde, Costa Rica is rapidly growing and the water quality is undoubtedly being affected. The Quebradas Rodriguez, Máquina, and Cambronero were sampled at three elevations to assess the water quality of the rivers according to the parameters used to calculate the Water Quality Index. Two additional parameters, depth and velocity, were also taken. The data showed that there is a positive correlation between dissolved oxygen and biochemical oxygen demand at the three rivers. There is also a negative correlation between total coliform of the aforementioned variables. A large increase in nitrates and turbidity as well as a decrease in dissolved oxygen in the Quebrada Cambronero was found immediately following the Productores de Monteverde hog farm yet no such changes were seen in the Quebrada Máquina, which ran by Monteverde's main road, and which experienced different anthropogenic influences. This difference is evidence that the water contamination at the Cambronero was due to the hog farm inputs. The Quebrada Cambronero recovered to its normal values for nitrates and dissolved oxygen but not turbidity downstream. Stream ecology, however, may still be affected by this contaminated zone.

RESUMEN

La región de Monteverde, Costa Rica esta creciendo rápidamente y la calidad de agua está siendo indudablemente afectada. Se probaron las Quebradas Rodríguez, Máquina, y Cambronero a tres elevaciones para evaluar la calidad de agua de los ríos según los parámetros usados para calcular el Índice de Calidad de Agua. También se tomaron dos parámetros adicionales, la profundidad y velocidad. Los datos mostraron que hay una correlación positiva entre la demanda de oxígeno disuelto y oxígeno bioquímico en los tres ríos. Hay también una correlación negativa entre el total de coliformes de las variables mencionadas. Un aumento grande en los nitratos y turbidez, así como una disminución en el oxígeno disuelto en la Quebrada Cambronero se encontró siguiendo inmediatamente la granja de cerdos Productores de Monteverde pero no se observó ningún cambio en la Quebrada Máquina que corre por el camino principal de Monteverde y qué influencias experimenta diferentes influencia antropogénicas. Esta diferencia es la evidencia que la contaminación del agua en Cambronero es debido a las entradas de la granja de cerdos. La Quebrada Cambronero recuperó sus valores normales en cuanto a los nitratos oxígeno disuelto pero no la turbidez río abajo. La ecología del arroyo, sin embargo, todavía verse afectada por está zona contmaninada.

INTRODUCTION

The region of Monteverde, Costa Rica has seen considerable expansion in the past few decades with a large influx of tourists, creating a booming local economy and an expanding populace. It has been well documented that one of the primary results of urban expansion is the increased contamination of streams (Walsh 2005). While there has been some work to collect data about the watersheds in Monteverde, Costa Rica (Kim 2002), the sparse literature does not include many physical or biological indicators that can be associated with *E. coli* levels, a vital indicator of the health of the stream.

Physical, chemical, and biological factors can all influence the dynamics of a stream's ecosystems. For example, oxygen consumption occurs at unique rates depending on the composition of a stream community (Allan 1995). This means that information about dissolved oxygen content in streams is not enough to elucidate the true biological integrity of a watershed—rate of input and output of oxygen is needed. Biochemical oxygen demand, the rate of change of the oxygen content due to aerobic requirements, and velocity of streams (which affects oxygen content) are needed as well. Low oxygen levels have been shown to correlate with coliform bacteria (Keylon 2008) that can upset sensitive invertebrate communities (Kerans and Karr 1994), and thus coliform bacteria serve as a canary in a coal mine to signal the degradation of a stream's invertebrate life forms.

The most critical manipulation of ecosystem dynamics is not the coliform bacteria itself, but rather the pollution from nearby residences and businesses that allow this bacteria to grow. Key point-sources of pollution are considered in this study to investigate their effects on the health of the stream. Dissolved oxygen content (DO), biochemical oxygen demand (BOD), stream velocity, depth, nitrate levels (NO_3), phosphorus levels (PO_4^-), total solids (TS), pH, turbidity, and temperature are measured so that relationships between these aforementioned factors and levels of coliform bacteria can be determined. These data can supply a valuable baseline data set that can be the foundation for a long-term monitoring program of the health of Monteverde's streams through establishment of the parameters that determine the Water Quality Index (WQI) Value (Brown et al. 1973). Although it will only allow a snapshot of the complicated dynamics of a stream, these data may provide a valuable, baseline prognosis of the health of key water sources in the rapidly growing Monteverde region. A long range monitoring program is also becoming more imperative with changing conditions in the Monteverde region hypothesized as a result of the Lifting Clouds Hypothesis (Pounds 1999).

Methods

Study Sites

Water samples for this study were collected in the Monteverde Region of Costa Rica during the wet season on two separate days, July 27th and August1st. This region includes Premontane Moist Forest, Lower Montane Moist Forest, and Lower Montane Wet/Cloud Forest. Three streams with distinctive levels of development were selected for contrasts of water quality: the Quebrada Rodriguez which runs through the town of Santa Elena and thus receives a high amount of anthropogenic waste, the Quebrada Máquina which transects primary forest and has only minimal amounts of development, and the Quebrada Cambronero, which receives water from the

Productores de Monteverde hog farm in two forms: treated waste water and water and farm runoff.

Sample Collection

Three sites at each of the three rivers were sampled, at locations about 100-200 meters apart from each other, which created a high, medium and low elevation sample gradient. Altitudinal congruence between rivers was limited by physical barriers such as sheer cliffs and dangerous falls. The Quebrada Rodriguez had sites at 1350 m (RA), 1200 m (RB), and 1125 m (RC). The Quebrada Máquina was sampled at 1425 m (QA), 1100 m (QB) and 1000 m (QC). The three sampling sites at the Quebrada Cambronero were at 1200 m (CA), 1100 m (CB), and 900 m (CC).The samples were taken before the daily rains; this was done to avoid changes of the quality of the samples due to the large influx of fresh rainwater (Singh 1998). Velocity, depth and temperature were measured on site and water samples were taken in packages specifically prepared or treated according to the type of test as described below.

Physical and Chemical Parameters

Temperature was assessed with a standard water thermometer placed in the middle of the running stream for one minute. Velocity was calculated by averaging the amount of time (sec) required for a ping pong ball to progress through one meter of the stream (n = 10 trials per site). The depth was measured with a meter tape at the deepest position at each site. One large, chemically untreated, yet clean glass jar was used to take the water sample used for turbidity and total solids. The water sample for DO was treated on site with Manganous Sulfate solution and Alkaline Potassium Iodide Azide to fix the oxygen content in the water sample as instructed by the LaMotte Dissolved Oxygen Test Kit. Two jars blackened with electrical tape were used to take the sample used for BOD with special vigilance against water bubbles in the sample that could manipulate the results. The sample was sealed on site with duct tape. The water sample for pH, NO_3 and PO_4 was taken in a jar treated with deionized water to ensure that no ions were present in the container prior to sampling. DO, BOD, NO_3, PO_4, Turbidity, and pH were tested with the LaMotte Water Testing Kit. All of the Lamotte water tests were done twice and the average of the values were taken. TS were measured by evaporating a 50mL sample and calculating the mass of the solid remaining.

Coliform Bacteria Sampling

Only two water samples were taken at two different sites along the Quebrada Máquina and the Quebrada Cambronero due to logistical constraints. To prevent contamination, the water sample was taken in new zip lock bags with no extra space for oxygen available. The water samples were plated the same day on Pall MicroFunnel™ Filter Funnels and MF-Endo agar following the manufacturer's instructions. The plates were inverted and incubated in an incubation device for 24 hours. After this time, the plates were removed and total coliform colonies were counted under a dissecting microscope and averaged. Only one water sample from the lowest elevation on the Cambronero survived for plating and thus the total coliform count could not be averaged for this site.

RESULTS

The results of the data collection are summarized in Appendix 1. An analysis indicates that there is a positive correlation between DO and BOD for the average values of BOD and DO at the three rivers (Figure 1). There is also a negative correlation between total coliform and both BOD and DO (Figure 2). There are three parameters that show jarring changes for the Quebrada Cambronero at the CB site, which is at 1100 m. The value of NO_3^- increases at 1100 m but recovers at 900 m. DO drops dramatically at CB, but likewise shows a recovery at the lowest elevation site. An increase is also seen in turbidity but does not show any recovery at 900 m. Neither the Quebrada Rodriguez nor the Quebrada Máquina shows this pattern.

Qualitative Site Assessment

The Quebrada Rodriguez originates above the town of Santa Elena and passes through town, where there are many open sources of contamination stemming from local residences and businesses. The river became a steep gorge once entering the Cañitas area yet had large tires, coffee sacks, and other assorted anthropogenic junk items scattered. The river continued this pattern, curving around to the Los Llanos area to form a loop around the greater Monteverde region.

The Quebrada Máquina originates above the Monteverde Biological Station and seemed unaffected by human waste until it passed a clear site of intrusion at the main road that transverses the Monteverde region. This small intersection had homes that deposited waste materials much like the Quebrada Rodriguez. The environment returned to a rather pristine condition following this particular area.

The Quebrada Cambronero originates in the town of Monteverde and passes through the Productores de Monteverde hog farm. This area had a strong odor reminiscent of fecal waste and carried noticeably dirty water. The river then continued until it plummeted into a waterfall that descended about 75m with smaller drops thereafter.

WQI Values

The Q values for the three rivers are located in Appendix 2, with the appropriate weight of these parameters and the corresponding WQI values calculated for MA, MC, CA and CC.

DISCUSSION

Figures 1 and 2 suggest that increased oxygen availability in streams as indicated by high levels of DO allow for more life, which is implied by the high BOD values in these streams. The positive correlation between these two factors may explain the negative correlation between DO and total coliform bacteria seen by Kaylan (1998). More oxygen in the streams would seem to support more life which allows for high oxygen consumption. A survey of the streams of Costa Rica done by Pringle and Ramírez (2007) showed that the invertebrate composition was dominated (>90%) by insects. This is also supported by Callisto et al. (2004). Thus, it can be hypothesized that in locations with conditions that are favorable for aerobic invertebrates such as insects, the conditions will probably not be suitable for coliform bacteria growth. When the conditions incline towards anaerobic conditions, there are much smaller insect populations and higher amounts of coliform bacteria. BOD and total coliform bacteria therefore seem to be two sides of the same coin—they both are indicators of DO levels available for consumption.

The green arrow in Figure 2 indicates the location of the Productores de Monteverde hog farm located at ~1180 m, which is a large source of water input into the river. This water input seems to be the cause of the changes seen at site CB and there is strong evidence that suggests that the poor quality of the input water rather than the quantity of the water coming from the hog farm is the factor that causes this change. A change of congruent magnitude in the values for nitrates, turbidity, and DO is not seen at the Quebrada Máquina following intersection with another well known source of water input into this river—the main road that intersects the Máquina at 1400 m (red arrow). The Quebrada Rodriguez, which runs through the main town, has anthropogenic inputs at numerous points rather than one concentrated input and had values that serve as a reference for both rivers. A hypothesis to explain the elevated nitrate levels from the hog farm is rather straightforward: the hog farm uses whey feed for their hogs. This, combined with runoff from cattle feces which is not treated in their water treatment pools (per. obs), should be enough to account for the elevated nitrate levels observed. The feces as well as the chemically treated water could also explain the elevated turbidity in the Cambronero. A possible reason for the low DO levels observed in our data is that the treatment pools at the Monteverde hog farm do not filter biological agents (Sarah Stuckey pers. comm.) following the removal of swine fecal matter.

In spite of the possible incursion by the Productors de Monteverde on the Quebrada Máquina, the steep waterfall downstream of the hog farm seems to effectively recover both the DO and the nitrate levels. The turbidity, according to our data, does not recover at the site collected but this is not as important of a factor to biological ecosystems as the prior two factors (Mitchell and Stapp, 1995). The recovery may be the reason why our WQI values do not reflect a large disparity between the quality of the Quebrada Máquina and the Quebrada Cambronero. It is important to also recognize that the main utility of the WQI lies in its ability to detect long term change in a wide breadth of parameters in future measurements.

It is still possible that this localized area of disturbance, even though it recovers downstream of the contamination site, affects the ecosystem downstream. Brittain and Eikeland (1987) discuss the importance of stream drift in macro invertebrate ecology; it is a key factor for colonization and distribution as well as population dynamics of downstream macro-invertebrate communities. Drift allows these organisms to escape predators and thus is a key function of the lives of stream macro invertebrates. An ecologically dead zone in the Quebrada Máquina due to extremely low oxygen levels and high nitrate levels could severely disrupt this mechanism. In addition, both Meyer and Johnson (2006) and Gulis and Suberkropp (2002) have found that the decomposition of leaf litter is affected by altered nitrogen dynamics in temperate areas, thus suggesting that the recycling mechanisms in the Quebrada Cambronero could be affected—although how this translates in the tropical latitudes is yet to be resolved. This information as well as further data collection for the WQI index would be insightful information for future studies to explore. Furthermore, the correlation between DO and coliform should be investigated to resolve the exact nature of this relationship.

ACKNOWLEDGEMENTS

I would like to thank Karen Masters for all of her logistical support, for all the trials and tribulations, and for all the tender loving care I have received to overcome those trials and tribulations over the course of this program. I am extremely grateful to Pablo Allen for all the day to day help and emergency care, Moncho Calderon for being a pillar of support, and Tania Chavarria for help with the equipment needed for this project. Special thanks go to my mother, father, and my little sister their patient guidance, unwavering love, and constant assistance. This also applies to the Delgado-Badilla family. I would also like to thank the staff at the Biological Station in Monteverde, Costa Rica for the excellent meal preparations and constant supply of coffee that made this project possible.

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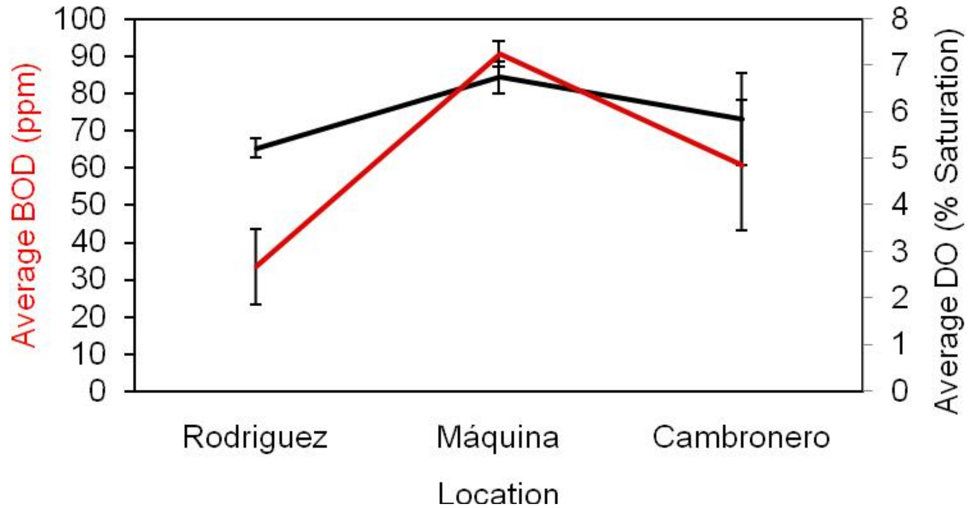

FIGURE 1. Correlation between average BOD (ppm O_2) and average DO (% saturation). This figure suggests that as the average DO increases, more oxygen is available for consumption and the waters have a higher rate of oxygen utilization thus accounting for the increased BOD.

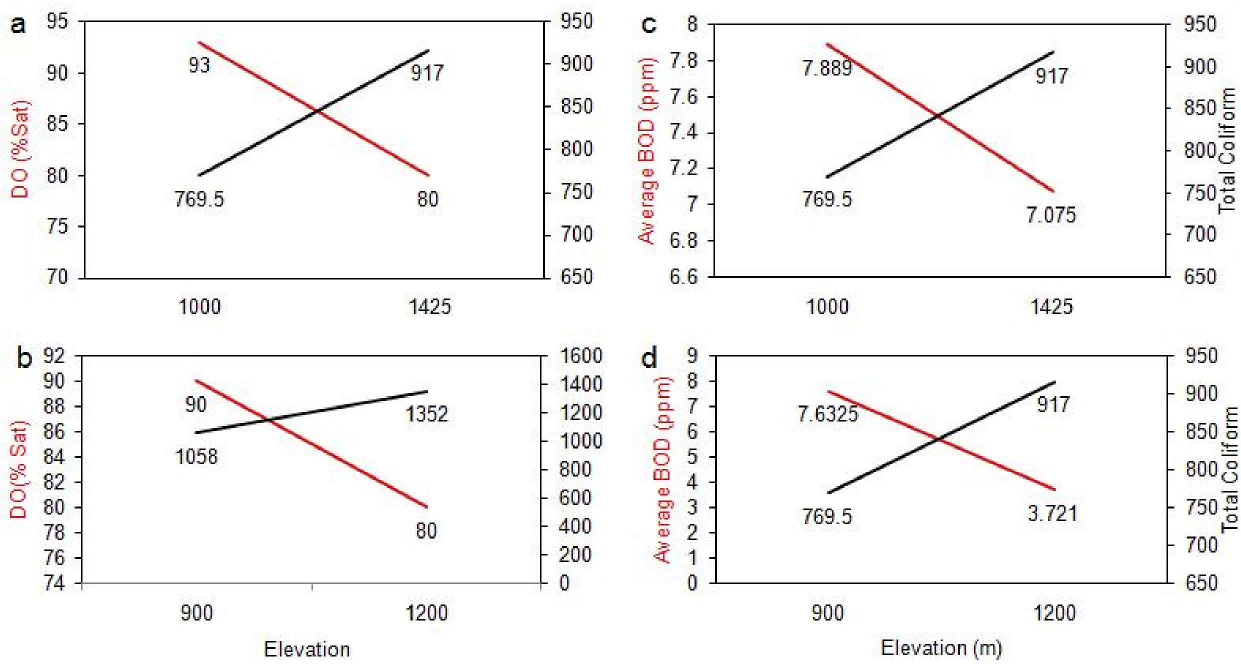

FIGURE 2. This figure shows the relationship of total coliform counts per 100ml sample with (a) DO as measured in percent saturation in the Quebrada Máquina, (b) DO as measured in percent saturation in the Quebrada Cambronero, (c) the average BOD in ppm at the Quebrada Máquina, and (d) the average BOD in ppm at the Quebrada Cambronero. Notice that only the highest and lowest altitudes of samples are included.

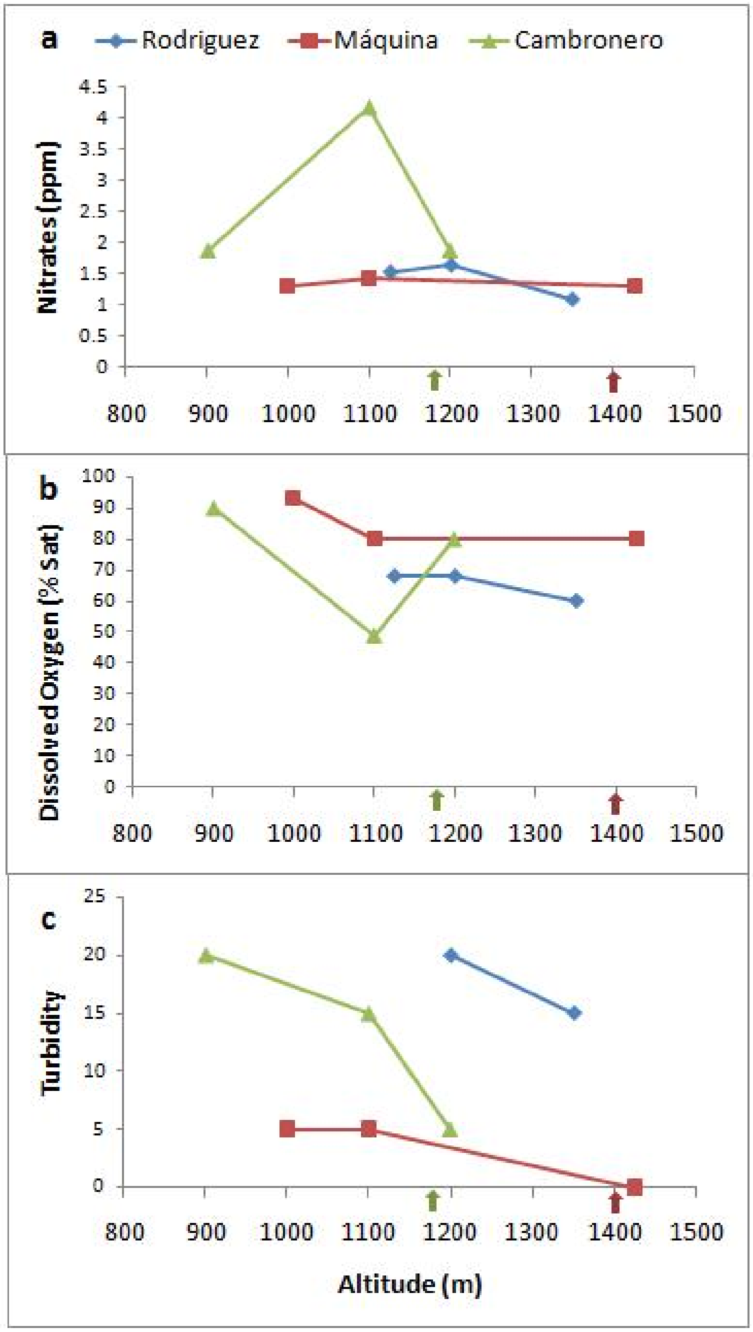

FIGURE 3. Nitrates (a), dissolved oxygen (b) and turbidity (c), three parameters that show extreme changes at the second sampling site on the Quebrada Cambronero, which is located following water input from the Productors de Monteverde hog farm at ~1180m (green arrow). The Quebrada Máquina is used as a reference for the effects of another well known site of water input from the main road which intersects at ~1400m (red arrow); this input has little or no effect on these three parameters. The Quebrada Rodriguez is a river that has no large points of intersection but has many smaller inputs deriving from its path through the town of Santa Elena, Costa Rica. These three parameters also show some recovery on the Quebrada Cambronero following a large altitudinal descent before the lowest elevation sampling site.

APPENDIX

APPENDIX 1. Data on physical and biological parameters of water quality at three streams (Rodriguez, R; Máquina, M; and Cambronero, C), at three elevations (A, B, and C).

Appendix 1	**RA**	**RB**	**RC**	**MA**	**MB**	**MC**	**CA**	**CB**	**CC**
Altitude (m)	1350	1200	1125	1425	1100	1000	1200	1100	900
DO (%Sat)	60	68	68	80	80	93	80	49	90
Coliform (Colonies/100ml)	X	X	X	917	X	770	1352	X	1058
pH	6.7	7	7	5	5	5	5	5	5
BOD(mg/l)	1.07	3.5	3.46	7.08	6.79	7.89	3.72	*3.22*	7.63
Nitrates(mg/l)	1.1	1.65	1.54	1.32	1.43	1.32	1.87	4.18	1.87
Turbidity (NTU)	15	20	X	0	5	5	5	15	20
Total Solids (mg/l)	980	960	700	1320	2380	720	900	1020	1400
Depth (m)	0.15	0.5	0.46	0.07	0.33	0.37	0.6	0.23	0.45
Temperature (°C)	18	18	18	16	17	17	21	21	20
Velocity (m/s)	0.323	0.139	0.370	0.204	0.263	0.303	0.250	0.227	0.385

Appendix 2. The Q values and their appropriate weights to assign a WQI value.

RA	Q Value	Weighting Factor	Total
1. DO (%Sat)	58	0.17	9.86
2. Fecal Coliform (colonies/100ml)		0.16	0
3. pH	68	0.11	7.48
4. BOD(mg/l)	95	0.11	10.45
5. Temperature (^{o}C)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	94	0.1	9.4
8. Turbidity (NTU)	68	0.08	5.44
9. Total Solids (mg/l)	20	0.07	1.4

RB	Q Value	Weighting Factor	Total
1. DO (% Sat)	75	0.17	12.75
2. Fecal Coliform (colonies/100ml)		0.16	0
3. pH	69	0.11	7.59
4. BOD(mg/l)	63	0.11	6.93
5. Temperature (^{o}C)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	91	0.1	9.1
8. Turbidity (NTU)	61	0.08	4.88

9. Total Solids (mg/l)	20	0.07	1.4

RC	Q Value	Weighting Factor	Total
1. DO (% Sat)	75	0.17	12.75
2. Fecal Coliform (colonies/100ml)		0.16	0
3. pH	69	0.11	7.59
4. BOD(mg/l)	63	0.11	6.93
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	92	0.1	9.2
8. Turbidity (NTU)		0.08	0
9. Total Solids (mg/l)	20	0.07	1.4
MA	Q Value	Weighting Factor	Total
1. DO (%Sat)	88	0.17	14.96
2. Fecal Coliform (colonies/100ml)	22	0.16	3.52
3. pH	28	0.11	3.08
4. BOD(mg/l)	48	0.11	5.28
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	93	0.1	9.3
8. Turbidity (NTU)	98	0.08	7.84
9. Total Solids (mg/l)	20	0.07	1.4
			64.68
MB	Q Value	Weighting Factor	Total
1. DO (% Sat)	88	0.17	14.96
2. Fecal Coliform (colonies/100ml)		0.16	0
3. pH	28	0.11	3.08
4. BOD(mg/l)	48	0.11	5.28
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	92	0.1	9.2
8. Turbidity (NTU)	85	0.08	6.8
9. Total Solids (mg/l)	20	0.07	1.4
MC	Q Value	Weighting Factor	Total
1. DO (% Sat)	96	0.17	16.32
2. Fecal Coliform (colonies/100ml)	26	0.16	4.16
3. pH	28	0.11	3.08
4. BOD(mg/l)	43	0.11	4.73
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10

7. Nitrates(mg/l)	93	0.1	9.3
8. Turbidity (NTU)	85	0.08	6.8
9. Total Solids (mg/l)	20	0.07	1.4
			65.09
CA	Q Value	Weighting Factor	Total
1. DO (%Sat)	88	0.17	14.96
2. Fecal Coliform (colonies/100ml)	20	0.16	3.2
3. pH	28	0.11	3.08
4. BOD(mg/l)	60	0.11	6.6
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	90	0.1	9
8. Turbidity (NTU)	85	0.08	6.8
9. Total Solids (mg/l)	20	0.07	1.4
			64.34
CB	Q Value	Weighting Factor	Total
1. DO (% Sat)	40	0.17	6.8
2. Fecal Coliform (colonies/100ml)		0.16	
3. pH	28	0.11	
4. BOD(mg/l)	67	0.11	7.37
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	69	0.1	6.9
8. Turbidity (NTU)	68	0.08	5.44
9. Total Solids (mg/l)	20	0.07	1.4
			47.21
CC	Q Value	Weighting Factor	Total
1. DO (% Sat)	95	0.17	16.15
2. Fecal Coliform (colonies/100ml)	21	0.16	3.36
3. pH	28	0.11	3.08
4. BOD(mg/l)	43	0.11	4.73
5. Temperature (^oC)	93	0.1	9.3
6. Total Phosphate(mg/l)	100	0.1	10
7. Nitrates(mg/l)	90	0.1	9
8. Turbidity (NTU)	62	0.08	4.96
9. Total Solids (mg/l)	20	0.07	1.4
			61.98