BELIZE RIVER WATER QUALITY- A BASELINE CHEMICAL ASSESSMENT

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Abstract

The Belize River continues to face pollution problems from industrial and domestic processes. The objective of this study, therefore, was to compare nutrient levels in the three reaches of the river and to determine the overall health. Samples were acquired using a Hach Hydrolab Sonde and a Niskin Water Sampler; laboratory analyses were done using a Hach DR 5000 Spectrophotometer. Results from water quality analysis indicated that the river was not in proper health conditions as the levels of nitrates, nitrites, ammonia and phosphates were elevated in all three reaches of the river. At the same time, all three reaches of the river displayed dissolved oxygen concentrations below 4mg/L, which can prove to be detrimental to aquatic life. However, this low dissolved oxygen concentration could be faulty reading by the hydrolab sonde as the river is very turbulent and therefore, should display high dissolved oxygen levels throughout the river. Nevertheless, the river is being directly and indirectly polluted from many different sources and the mitigation measures would therefore have to be more complex.

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GLOSSARY

A.

Ammonia- a compound of nitrogen and hydrogen (NH3 or HN4+).

ANOVA- Analysis Of Variance (statistical model used to analyze difference between groups)

D.

DOE- Department of the Environment (Belize)

DO- Dissolved Oxygen (the relative measure of the amount of oxygen that is dissolved in a given medium)

N.

Nitrate- a by-product of nitrifying bacteria (NO3).

***Nitrite*-** an ion with the formula (NO2-)

P.

Phosphate- an inorganic chemical with the formula PO_4^{3-}.

S.

Salinity- saltiness or dissolved salt content in a body of water.

SCORE- South Carolina Oyster Restoration and Enhancement Program.

T.

Tukey HSD- Tukey's Honestly Significant Difference test

U.

UNESCO- United Nations Educational, Scientific and Cultural Organization

US EPA- United States Environmental Protection Agency.

W.

***Water Temperature*-** temperature of a water body (^{o}C or ^{o}F).

WHO- World Health Organization

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INTRODUCTION

Surface water quality is a matter of serious concern today, as rivers are among the most vulnerable water bodies and are easily polluted (Singh, Malik & Sinha, 2005). The Belize River is currently under such stress as not only is the river being affected by high extraction rates, but also by pollution from both domestic and industrial processes (Boles & Karper, 2004). This results in poor water quality, an issue that can have adverse effects on both the health of aquatic organism and humans (Rosli & Yahya, 2012). While in the past the focus of a water quality assessment was mainly on the presence or absence of microbes, there has been growing awareness of the need to understand its chemical composition (Rostocil, 2009). For that reason, this research sought to assess the physio-chemical health of the Belize River, predicting elevated levels of nutrients in the lower reach.

The significance of water varies widely from consumption, use in industrial processes and use in agricultural irrigation, to its use in recreational activities (Kaushik *et al.,* 2012; Radwan *et al.,* 2003). In a country that is highly dependent on agriculture for foreign exchange earnings, it is no surprise that majority of the commercial farms and other developments are located near the largest water source in the country, the Belize River (Boles & Karper, 2004). Being the most highly used river, constant monitoring of water quality is necessary, however, little to no monitoring is currently done on the Belize River. The last research conducted and published on the Belize River water quality was in 1980 by Victor J. B. Gonzalez, whose work was more in the line of a qualitative study rather than quantitative. Gonzalez (1980) found that the levels of pollution were increasing as the population of Belize increased and made note that the country lacked proper water management, an issue that persists today.

Belize's economy is largely agriculture based, hence, the most important issue facing the Belize River is runoff or non-point source pollution; reported by the US EPA to be responsible for more than 60 percent of surface water contamination (Mishra, Singh, & Singh, 2010). While it is known that most compounds exist in the river naturally due to the various biogeochemical cycles, the use of fertilizers greatly increases the levels of some of them, mainly Nitrates and Phosphates (Keck & Lepori, 2012). Other organic compounds, disinfectants, pesticides, herbicides and other chemicals are also introduced to the river via runoff; they can cause severe eutrophication of the Belize River (Cardinale, 2011; Rostocil, 2009). Eutrophication is a complex process which occurs both in fresh and marine waters where excessive development of certain types of algae disturbs the aquatic ecosystems and becomes a threat for animal and human health (WHO, 2002).

It has been predicted that with the rapid population growth along the river, including urbanization and commercial farmlands, the Belize River would be subjected to increased pressure from pollution (Boles & Karper, 2004). Gonzalez's (1980) findings indicate that the pressure from pollution and lack of proper water management is an issue that has been ongoing for decades. While there is currently a national water management plan, it is not yet being fully utilized. Supporting effluent limitation regulations were set in place by the Department of the Environment, however, monitoring and control is seriously lacking, mainly due to limited financial backing from the Central Government of Belize. Therefore, it was left in the hands of the scientific community to determine the health of the river.

This study gathered data on the major physiochemical parameters analyzed in water quality. Those parameters include ammonia, dissolved oxygen, salinity, pH, water temperature, nitrate, nitrites, phosphates, turbidity, and conductivity. The fore-mentioned parameters were gathered in the three reaches of the Belize River; Upper, Middle and Lower. The purpose was to identify similarities or differences in nutrient levels for the three reaches, to determine which section is the healthiest, and to determine the overall health of the river as a unit. This information can serve as a baseline for future studies on the Belize River and can serve as a baseline for decision making regarding effluent regulations. Given that majority of Belize's population utilizes this river one way or another (Boles & Karper, 2004), it was crucial that this information be gathered.

BACKGROUND

Data on water quality in rivers of Belize

Belize is a country with many freshwater sources including rivers and lakes. Currently, majority of Belizeans obtain water and fish from the largest river, The Belize River (Boles & Karper, 2004). Internet research and personal communication with various government departments resulted in few articles regarding water quality in Belize, especially its rivers. One study found is that of Victor J. Gonzalez (1980), entitled, "A Limnological Investigation Of A Tropical Fresh-Water Ecosystem: The Belize River, Belize, Central America".

Gonzalez (1980) cited a 1960 hydroelectric feasibility study done on the Belize River by R. L. Walker, where Walker suggested that a hydrometric survey be done to gather essential data that would be used to guide future developments of hydroelectric power. Hickok did a follow-up study to Walker in 1964 to evaluate the existing hydrologic data to prepare preliminary plans and cost estimates for the hydrologic studies needed to determine the future water needs of the people of Belize City. According to Gonzalez (1980), permanent gauging stations were not maintained on the Belize River and reliable dry-season or low flow measurements were not found, an issue still plaguing Belize today. Gonzalez also cited the previous findings of Walker (1970), who found that the pH of the Sibun and Belize river were a constant 7.5 unit; sodium chloride levels were between 68 and 138 mg/L; total dissolved solids between 640 and 5000 mg/L and hardness from 479 to 547 mg/L. According to Gonzalez, at the time of his study, in 1980, and Walker's study, in 1970, the country lacked proper planning and riparian legislations. Gonzalez (1980) concluded that Belize needed a coordinating body for the task of data collection, policy formation, planning, and legislation regarding water use. Today, there is a national water management plan; however, it is still not being fully utilized.

A document produced in 2001 by AMEC E&C SERVICES LIMITED/Canadian International Development Agency for BECOL entitled, "Macal Upstream Storage Facility Environmental Impact Assessment- Part 2 Support Documents" also looked at various water quality parameters for the Macal River, a tributary river to the Belize River. They found water temperature (18.8-26^{o}C), dissolved oxygen (>4 mg/L) to be in normal ranges; ammonia, nitrites and phosphates were below the limits of detection utilizing the best equipment at that time. Turbidity and pH were also within normal ranges according to the CIDA criteria (See Appendix 1-3). The study concluded that the overall water quality of the Macal River is generally good. However, further downstream, near San Ignacio showed signs of increased mineralization: increased hardness, alkalinity, conductivity, and TDS (AMEC, 2001).

Tunich-Nah Consultants (2000) also conducted water quality tests on the Macal River and Belize River from the Chalillo Damn downwards. Study sites included Monkey Tail, Kenloch, Bailarina Road, Guacamallo Bridge, Cristo Rey Village, Spanish Lookout Bridge, Guanacaste National Park and Burrel Boom Bridge. The document covered parameters such as pH, Salinity, Dissolved Oxygen, Nitrates, and Phosphates. The result from the water quality analysis can be viewed in Appendix 4-5. Preliminary results indicate that the rivers are healthy. A study done in 2008 by on the tributary streams was that of the Belize Solid Waste Management Project Environmental Impact Assessment Revised. The purpose of this particular study was to determine the contents of runoff from the new dumpsite at Mile 3 and 3 ½ near Belize City. The reason for the assessment is that the runoff streams lead directly into the lower reach of the Belize River (BET, 2008). The study found that the nitrate, nitrites and the variousy other parameters were within normal levels, i.e. below the maximum limit set by the US EPA for each parameter.

Ecoworks (2008), also conducted water quality assessments within the Mountain Pine Ridge Forest Reserve for a Granite Quarry proposed by Carribean Investors, LLC. The Environmental Impact Assessment covered water quality parameters such as pH, Temperature, Dissolved Oxygen, Nitrates, Sulphates & Phosphates, Total Suspended Solids and Hardness for Pinol Creek, a tributary stream to the Macal River. According to the results of the EIA, all parameters were within normal ranges, further supported by the presence of particular fishes. In the South of Belize, Esselman (2001) conducted minor water quality assessment on the Bladen and Swasey rivers. In his study, he found that Bladen had an average pH of 7.10 while Swasey had an average of 9.20, indicating that the Swasey River was much more alkaline. Nitrate levels for both rivers were within normal ranges, 0.22 mg/L and 0.01 mg/L respectively. Rostocil (2009), found that the analysis of the water in the New River Lagoon and those of its tributary streams (Bergen's Creek, Ramgoat Creek, Harry Jones Creek, and Irish Creek), showed low levels of phosphorus with a value of 5ppm, with the exception of Bergen's Creek which had a concentration of 30ppm. Nitrate levels were no higher than 2ppm for the New River Lagoon and the tributary streams, well below the 10 ppm maximum limit set by the US EPA (Rostocil, 2009).

Nutrient Enrichment/Eutrophication

Eutrophication refers to the complex process which occurs in waters whereby there is an increase in plant and algal production caused by excessive inputs of nutrients such as nitrates and phosphate, both obtained from fertilizers, sewage treatment and naturally (WHO, 2002). Over the past 50 years, eutrophication has been one of the leading causes of water quality impairment (Selman, Greenhalgh, Diaz & Sugg, 2008). However, in freshwater ecosystems such as the Belize River, the main cause of this impairment is normally phosphorus in the form of phosphates (Selman & Greenhalgh, 2009). A major problem in identifying the source of the pollution to mitigate it is that majority of the time the cause is non-point source (Mishra, Singh & Singh, 2010). In developing countries such as India and in this case, Belize, intensive runoff and transport of sediment along with agrochemicals are rapidly polluting water resources (Mishra, Singh & Singh, 2010). According to Selman & Greenhalgh (2009), there are indirect and direct drivers of pollution. Indirect drivers include population growth; economic growth (impacts consumption by consumers); and development of intensive agriculture (Selman & Greenhalgh, 2009), as with majority of the farms near the Belize River. Direct drivers of eutrophication include; higher energy consumption, increased fertilizer usage and land use changes (Selman & Greenhalgh, 2009).

Two of the most commonly recognized signs of eutrophication include algal blooms and hypoxia. These algal blooms can cause fish kills, human illnesses through food poisoning, and death of marine animals and birds (Selman, Greenhalgh, Diaz & Sugg, 2008). Hypoxia on the other hand, is considered the most severe symptom of eutrophication as it constitutes the complete depletion of oxygen in a body of water such as parts of the Gulf of Mexico and the Black Sea (Selman, Greenhalgh, Diaz & Sugg, 2008). Belize has also witnessed several algal blooms in the Southern parts of the country, attributed mainly to agricultural runoff from the many farms found in the South.

Background on parameters tested

Excess levels of certain compounds have the ability to directly affect the health of humans. For instance, high nitrate levels can cause methemoglobinemia, congenital malformation or deaths in infants (US EPA, 2006; Rostocil, 2009). Nitrate is a naturally occurring ion that forms a part of the nitrogen cycle. The Nitrate ion (NO_3^-) is the stable form of nitrogen in oxygenated systems (WHO, 2011). It is found mainly in fertilizers and is often used as an oxidizing agent, and in the production of explosives and in some cases, used in the production of glass (WHO, 2011). Nitrates are also used as a source of much needed nitrite, but become problematic when they reach surface and groundwater; mainly due to agricultural activities via excessive application of inorganic nitrogenous fertilizers and manures, from wastewater treatment, and from oxidation of nitrogenous waste products in human an animal excreta (WHO, 2011). Nitrite (NO2-) is also naturally-occurring, resulting from the oxidation of ammonia, however, it is often used in rodenticides (US EPA, 2007; WHO 2011). While the presence of nitrite on its own in a water body does not necessarily indicate a problem, the combination of nitrites with nitrates and ammonia indicates serious environmental pollution (Health Canada, 1987). According to Health Canada (1987), Nitrite levels should not exceed 3.2 mg/L or serious health issues may be experience. For instance, as with Nitrate, overexposure to nitrites causes methemoglobinaemia in infants (US EPA, 2006; Rostocil, 2009).

The presence of ammonia at elevated levels is an important indicator of fecal pollution; it can cause bad taste and odor as well as decrease the efficiency of disinfectants (WHO, 2003). Phosphates, on the other hand, do not have as adverse effects on humans but does contribute greatly to eutrophication (WHO, 2002). Another major component in river health is dissolved oxygen. Dissolved oxygen is the surrogate variable for the general health of an aquatic eco-system (Kaushik *et al.,* (2012). The processes that combine to determine DO levels include primary production, gross respiration of all components of an ecosystem, as well as physical aspects like turbulence, wind speed and water temperature (Addy & Green, 1997; Caraco *et al.,* 2000). Dissolved Oxygen levels are affected by various other parameters including salinity. Although it is generally not a concern in most freshwater lakes, it can greatly affect oxygen solubility in water bodies; higher salinities reduce the amount of oxygen that can be dissolved in a body of water (Addy & Green, 1997; Kramer, 1987). Even with high dissolved oxygen levels, there is always the possibility of drastic fluctuations, a normal occurrence in some ecosystems (Abowei, 2010; Addy & Green, 1997; Huggins & Anderson, 2005)

Water temperature plays a key role in many aspects of river health also. According to Kramer (1987), oxygen concentration in saturated water is reduced by an increase in water temperature. Clark (1996) identified temperature as being the most significant abiotic factor affecting key physiological, biochemical and life history of fishes. Another major parameter is pH; the World Health Organization (2003) defines as a measure of the acid-base equilibrium, which in most natural waters is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system. Aquatic organisms require the pH of a water body to be within a certain range so as to allow for optimal growth and survival; the ideal range being between 6.5 and 8.0 pH (Addy, Green & Herron, 2004). A pH outside of this range causes organisms to become physiologically stressed and in some cases affect their reproductive capabilities (Addy, Green & Herron, 2004). According to Mesner and Geiger (2010), a pH below 4 or above 10 will kill most fish. The effects on humans however, vary from eye irritation and skin disorders to severe gastrointestinal irritation, all depending on the sensitivity of the individual and the pH (WHO, 2003).

Adding to this, water quality is also affected by turbidity. Turbidity when in high levels does not only cause aesthetic problems but also health problems given that it can contain toxins such as heavy metals and biocides and can also harbor pathogens, leading to waterborne disease outbreaks (Health Canada, 2003; US EPA, 1999). Turbidity is partly affected by conductivity, as high conductivity levels will significantly decline turbidity (US EPA, 2013). Conductivity is indicative of river health. It is indicative of the ability of a water body to pass an electrical current and indicates the presence of inorganic dissolved solids such as chlorides, nitrates, sulphates, and phosphate anions (US EPA, 2012). It is an important parameter as a drastic increase in conductivity most likely means pollution is occurring (US EPA, 2012). The phosphate anion is also detrimental to the health of the aquatic ecosystem as it is a major contributor of eutrophication (Selman & Greenhelgh, 2009). According to the USGS via Litke (1999), studies on pristine streams indicate that a phosphate enrichment of as little as 0.01 mg/L can stimulate abundant algal growth and severely affect aquatic life. The source of the phosphate varies from point to non-point source pollution. Point source pollution of phosphates includes waste water treatment or industrial discharges while non-point source includes nutrient leaching from agricultural lands via manure or fertilizers (Mylavarapu, 2008).

METHODOLOGY

Study Area

The Belize River is the largest and most important river in Belize as greater than 45% of the country's population live near and depend directly on the river and its resources (Boles & Karper, 2004). The river itself is very shallow in the upper reach with an average depth of one meter; the mid-reach is much deeper, with some areas being as deep as five meters; the deepest area is the lower reach, in some areas it can reach a depth of roughly seven meters.

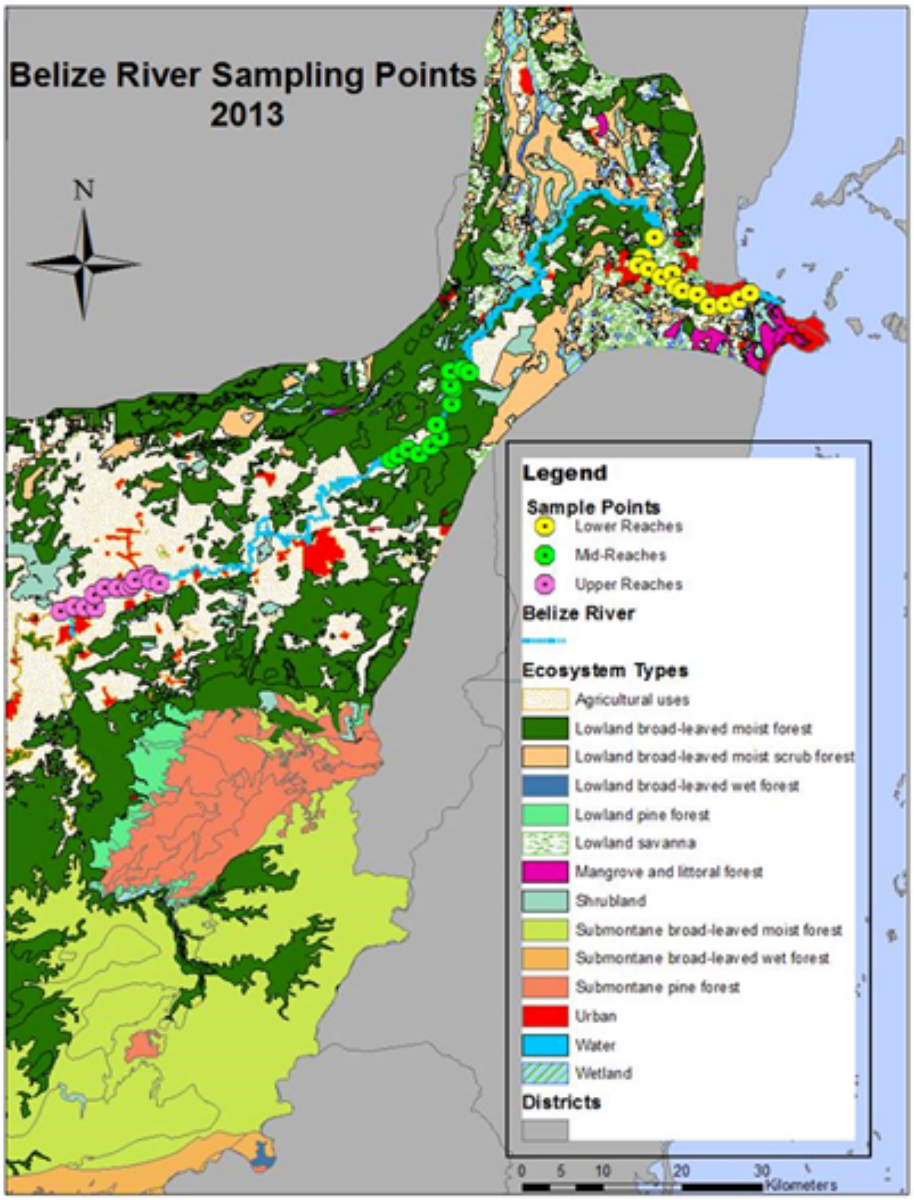

Figure1. Map of sampling points along the Belize River. Upper, Middle and Lower reaches inclusively.

Sampling and Fieldwork

Various sampling sites (2.2 kilometers apart) were located at the upper, middle and lower reaches of the Belize River. The distance between samples was tracked using a Garmin GPS (Appendix 7-c). Sampling was carried out on a three-day time span, with thirteen sampling sites being located and sampled in all three reaches of the river. The data collection was conducted in the middle of the river to ensure minimal influence from erosion banks and decomposition hotspots and from the influence of the riparian forests, especially on water temperature.

Surface water samples were collected at depths of approximately 0.5 meters using the Hydrolab Sonde (Appendix 7 b) and the Niskin Water Sampler (Appendix 7 a). They were directly stored into sanitized 120ml Nalgene bottles then deposited in an icebox at 0^{o}C and later transported to an appropriate storage facility at the University of Belize where they were kept at temperatures below -10^{o}C. Measurements of parameters such as dissolved oxygen, salinity, pH, temperature, ammonia, conductivity and turbidity were done *in-situ* at the various sampling stations. This data was collected via a comprehensive Hach Hydrolab Sonde and was stored on a laptop computer.

Laboratory Analyses

All analyses were done using the Hach DR 5000 spectrophotometer and Hach reagents. Nitrate levels were analyzed using the Cadmium Reduction Method. In this method, cadmium metal reduces nitrates in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. The reagent used in this analysis was the NitraVer® 5 Nitrate Reagent Powder Pillow. The analysis of Nitrites was completed using the Ferrous Sulfate Method. This method uses ferrous sulfate in an acidic medium to reduce nitrite to nitrous oxide. Ferrous ions combine with the nitrous oxide to form a greenish-brown complex in direct proportion to the nitrite present. The reagent used in this analysis was the NitriVer® 2 Nitrite Reagent Powder Pillows. Phosphate was analyzed using the PhosVer3 (Ascorbic Acid) Method. This method employed the use of the PhosVer® 3 Phosphate Reagent Powder Pillow produced by Hach. In the reaction, orthophosphate reacts with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue color.

Statistical analyses

Data was analyzed using the statistical software package: IBM SPSS 20. Various tests were employed for the testing of different variables: ONE WAY ANOVA for the comparison of means; Post Hoc Test to determine varitations; Levinne's Homogeneity Test.

RESULTS

Table 1

Summary of the water quality analysis done utilizing both the Hydrolab Sonde, and the HACH DR 5000 spectrophotometer. Values represent the mean of thirteen samples done in each reach of the river.

Factor	Concentration			Statistics
	Upper	Middle	Lower	P. Value
Ammonium ion (mg/L)	8.15 ± 0.49	6.42 ± 3.55	11.96 ± 1.06	0.000
Unionized Ammonia (mg/L)*	3.59 ± 0.22	3.25 ± 1.79	6.06 ± 0.55	-
Nitrates (mg/L)#	1.52 ± 0.20	1.80 ± 0.32	1.03 ± 0.14	0.000
Nitrites (mg/L)#	4.31 ± 2.32	6.08 ± 0.95	4.69 ± 0.63	0.012
Dissolved Oxygen (mg/L)	1.33 ± 0.27	3.28 ± 2.13	2.36 ± 0.80	0.003
Salinity (psu)	0.13 ± 0.01	0.16 ± 0.04	1.68 ± 0.99	0.000
pH (units)	8.76 ± 0.08	8.76 ± 0.07	8.76 ± 0.05	0.990
Temperature (celsius)	28.43 ± 0.27	29.47 ± 0.20	30.32 ± 0.35	
Phosphates (mg/L)#	0.38 ± 0.06	0.50 ± 0.13	0.45 ± 0.10	0.012
Turbidity (NTU)	1	1	1	-
Conductivity (mS/cm)	0.3 ± 0	0.32 ± 0.08	3.08 ± 1.77	0.000

* The Hydrolab Sonde was only able to measure the ammonium ion concentration and not TAN, however, un-iodized ammonia was calculated using the data in Emmerson, et al. (1975). # Values were measured using the HACH DR 5000 spectrophotometer while the rest were measured using the Hydrolab Sonde.

Table 2

Summary of the health rating per section.

Factor	Concentration		
	Upper	Middle	Lower
Ammonium ion (mg/L)	Elevated	Elevated	Elevated
Unionized Ammonia (mg/L)	Elevated	Elevated	Elevated
Nitrates (mg/L)	Normal	Normal	Normal
Nitrites (mg/L)	Elevated	Elevated	Elevated
Dissolved Oxygen (mg/L)	Low	Low	Low
Salinity (psu)	Normal	Normal	Elevated
pH (units)	Normal	Normal	Normal
Temperature (celsius)	Normal	Normal	Normal
Phosphates (mg/L)	Elevated	Elevated	Elevated
Turbidity (NTU)	Normal	Normal	Normal
Conductivity (mS/cm)	Normal	Normal	Normal
POINTS	7	8	1

Darker red indicates higher deviation from the acceptable level. Green indicates that the concentrations are within acceptable levels. Rating developed by researcher and is based on acceptable levels stated by US EPA, Health Canada, WHO and British Columbia Ground Water Association.

DISCUSSION

Chemical Analysis

The chemical nature of the river varied highly from point to point, with ammonium ion (NH_4^+) concentration showing higher levels in the upper and lower reaches of the river. It is speculated that this is due to agricultural and domestic establishments, as can be seen in Figure 1. These developments dominate the upper reach, while urban development dominates the lower reach. The lower reach is also the section of the river where settling occurs due to lower water speed, therefore, it is not rare to find higher concentrations of chemicals in the lower reaches of a river (Rosli & Yahya, 2012). Nevertheless, both of the values (see Table 1) were above the 6mg/L-N of ammonia naturally contained in surface waters (Health Canada, 2012). The middle reach of the river also contained concentrations of ammonium ion slightly higher than the natural levels. The calculation of unionized ammonia, done based on the principles of Emerson et al., (1975), showed that the concentrations were well within toxic levels for fishes (see Table 1). While the mid reach also had higher than normal concentrations of unionized ammonia, the region had very lotic waters due to the many rapids present. Lotic waters result in contaminants being carried downstream rapidly (Rosli & Yahya, 2012). Furthermore, during the sampling period, the mid reach suffered severe precipitation, which resulted in partial dilution of the surface water. Therefore, it is possible and highly likely, that the lower concentrations observed in the mid reach was due to the precipitation factor. As can be seen in Table 1, ammonium ion and unionized ammonia showed the highest standard deviation in the mid reach. In the case of the elevated levels of ammonia, there is the potential for serious repercussions on humans. This is so, as ammonia is known to have a very toxic effect on humans when the intake becomes higher than the body's ability to detoxify (WHO, 2003). The problem in dealing with high levels of ammonia in a water body is that the pollution is often from non-point source such as agricultural, residential, municipal, and atmospheric releases (Canadian Council of Ministers of the Environment, 2010).

Nitrate-nitrogen was also measured for all three regions of the Belize River as shown in Table 1. The most significant nitrate-nitrogen concentrations were found in the mid reach of the river (1.8 mg/L). The lowest concentration was found in the lower reach of the river (1.0308 mg/L) and the mid average was found in the upper reach (1.5154 mg/L). The British Columbia Ground Water Association (2007), state that the maximum acceptable concentration for nitrate-nitrogen is 10mg/L. Therefore, all three regions displayed nitrate-nitrogen concentrations within the maximum allowable concentration set by the British Columbia Ground Water Association. If the nitrate-nitrogen increases beyond the maximum allowable concentration, consumers could potentially face methemoglobinaemia. Substantial increases in this nutrient can also trigger mass eutrophication as seen with the rivers to the South of the country. However, while it was concluded that the concentration levels were normal, it is believe that as with the other physio-chemical parameters, there was a serious influence by the precipitation level that was experienced.

Nitrite levels (see Table 1) in this case were all above maximum allowable concentration of 3.2 mg/L set by Health Canada (1987). The highest value, almost double of MAC, was recorded in the mid reach of the river; a value of 6.0769 mg/L. The second highest value was recorded in the lower reach of the river, a value of 4.6923 mg/L. The lowest value of 4.3077, recorded in the upper reach of the river was also still above the maximum allowable concentration. The mid reach had the highest nitrite levels. This could be due to the high forest cover and endless debris in the water, where decomposition would be resulting in increased nitrite levels. It could also be that while the immediate area was not deforested, all the runoff from the farms in a distance was reaching the river via the many tributary streams that lead into the river. The upper reach had very lotic waters and hence, the nitrite would have been carried downstream rapidly. As for the lowest reach having had a lower concentration than the mid reach, it could be that plants were using it up. However, no definitive statement can be made as to the reason for the lower concentration level. Nevertheless, if the levels continue to increase and people continue to consume the untreated water from the river, there could potentially be new cases of methemoglobinaemia in Belize as that is one of the main problems with high levels of nitrite (Health Canada, 1987; Rostocil, 2009; US EPA, 2006).

Dissolved oxygen, on the other hand, showed an alarmingly low average concentration level in all reaches of the river, ranging from 1.33 to 3.27 mg/L (see Table 1). The upper reach had the lowest average dissolved oxygen concentration of just over 1mg/L. The mid reach had the highest average of around 3.27 mg/L. The lower reach had an average of 2.36 mg/L. In this case, although the upper reach had the most rapids of all three reaches, it also showed the lowest concentration of dissolved oxygen. It is known that as water temperature increases, dissolved oxygen level decreases, a normal occurrence in water bodies (Kramer, 1987). Water temperature is dependent mainly on the exposure of the water body to sunlight, however, the sky was cloudy for majority of the sample period, therefore, the effect of sunlight on water temperature would not be as dramatic. As seen in Table 1, the upper reach had a normal temperature; in fact, it had the lowest temperature of all three reaches. Therefore in looking at the dissolved oxygen level in the upper reach, it can be attributed to faulty readings by the Hydrolab Sonde. The mid reach also had numerous rapids and was in fact substantially deeper than the upper reach. Therefore, it was not surprising to see that it had a higher DO concentration than the lower reach, which had the lowest. During the sampling of the lower reach, the exposure of the river to the sun was minimal as it was cloudy most of the time and hence, the temperature of the water would have been around normal, not adversely affecting oxygen solubility. The lower reach of the river had an average below the minimum acceptable limit of 4 mg/L as state by Kramer (1978). It was also the section that had the most attention recently, due to hundreds of fish kills near Belize City in 2012. For fish and other organisms to survive in a body of water, the dissolved oxygen level must be at minimum 4mg/L saturation or the aquatic systems and even human health are adversely affected (Abowei, 2010; Caraco *et al.,* 2000; Kaushik *et al.,* 2012; Radwan *et al.,* 2003; WHO, 1978). According to Mr. Juan Martinez of St. Mathews village in the Belize District, Tilapia is the main fish found in the Belize River. This is because most other fishes die when the dissolved oxygen concentration falls below 4 mg/L (Caraco *et al.,* 2000; Kaushik *et al.,* 2012). Tilapia on the other hand is highly tolerant of low dissolved oxygen concentration and can even tolerate as low DO as 0.1 mg/L, given that other parameters are normal (Mjoun, Rosentrater & Brown, 2010).

The river showed a normal salinity gradient throughout the river, including the lower reach near the mouth. The average salinity concentration ranged from 0.1308 to 1.6815 ppt/psu as shown in Table 1. The upper reach had the lowest salinity with a value of 0.1308 ppt/psu; the mid reach had the median salinity value of 0.1554 ppt/psu; and the lower reach had the highest salinity value of 1.6815 ppt/psu. The low salinity levels in the upper and mid reaches are generally attributed to their relative distances from the sea. Also, in the case of the mid reach, given that during the survey there was a down pour of precipitation, that would have also acted as a dilution factor. The higher salinity concentration in the lower reach was expected due to its proximity to the sea. Based on the ranking, water is considered fresh when the salinity is below 0.5ppt/psu; considered brackish between 0.6 and 30 ppt/psu; considered salty above 30 ppt/psu (Vaz, Dias, Leitao & Martins, 2005; UNESCO, 1981; UNESCO, 1985). Therefore, it can be concluded that the Belize River is not experiencing salt water intrusion and can be considered fresh, with the exception of the lower reach. The case with the lower reach can be attributed to lower water level in the river due to the recent dry season. In cases where the salinity of a river is very high, there are numerous effects on organisms and humans. A drastic increase in salinity would mean increased pressure on Belize Water Services Limited to provide its customers with potable water, as they would have to invest heavily on desalination equipments. In addition, for people who consume water directly from the river, it would mean a slightly saltier taste; however, it should not pose significant health risks except in cases where people need to regulate their daily salt intake due to hypertension, diabetes or other related diseases (Department of Health, 2008). High salinities would also affect aquatic organisms' ability to maintain optimal internal osmotic concentration required for survival (Dunlop, McGregor & Horrigan, 2005)

Table 1 shows that the average pH of the river ranged from 8.76 units. All three reaches had an average pH of 8.76 units. Normally, a higher pH level is expected in the lower reach of the river due to the mixing of the seawater with fresh water (SCORE, 2013), however that was not the case in this study. The Effluent Limitations Amendment Regulations (2009) of Belize states that an acceptable pH range for a river is between 5 and 10 units, therefore it can be concluded that all three reaches are normal in pH levels. This is a desired result as according to Mesner and Geiger (2010), a pH below 4 or above 10 will kill most fish. This result is not substantially different from the findings of Amec and Tunich Nah (Appendix 3 & 5 respectively). Given the average pH observed, there would be no real influence on the ammonia concentration.

Water temperature plays a very important role in rivers. As stated by Clark (1996), it is the most significant abiotic factor affecting key physiological, biochemical and life history of fishes and other organisms. The result in Table 1 shows an average temperature range of 28.43 and 30.32 ^{o}C. The upper reach showed the lowest average temperature of all the three reaches while the mid reach showed the second highest/lowest average. The lower reach had the highest water temperature of all three reaches. However, according to Abowei (2010), natural inland waters in the tropics generally varies between 25 ^{o}C and 35^{o}C, therefore, all reaches of the river had normal temperatures. This is important as the temperature of the water directly affects the dissolved oxygen level; the higher the temperature, the lower the DO concentration and vice versa (Kramer, 1987). Water temperature outside of this range would also slow down metabolic processes, slow down the rate of photosynthesis of aquatic plants, alter reproduction cycles and alter the geographic distribution of species as some would migrate (SCORE, 2013). The temperature of the water is partly dependent on the rate of flow and exposure to sunlight. In this case, the sky was fully cloudy most of the time; hence, there would be little influence from the sunlight on the water temperature.

Phosphates are also a major component of water quality, contributing greatly to eutrophication (Selman & Greenhalgh, 2009; WHO, 2002). The results as shown in Table 1 indicate that the highest concentration of phosphates was in the mid reach with a value of 0.50 mg/L. The second highest concentration of 0.45 mg/L was recorded in the lower reach, and the lowest concentration was observed in the upper reach of the river being 0.38 mg/L. While these levels may seem low, according to the USGS via Litke (1999), a phosphate level as low as 0.01mg/L can have detrimental effects on aquatic ecosystems by causing severe algal blooms. According to the criteria set by the US EPA (1986), a water body such as the Belize River, should not exceed phosphate levels of greater than 0.01 mg/L. Therefore all three reaches are displaying signs of high phosphate levels and must be addressed immediately to prevent a serious occurrence of eutrophication.

Turbidity is known to affect light penetration in water bodies and can harbor pathogens, leading to disease outbreaks (Health Canada, 2003; US EPA, 1999). Table 1 shows that all three reaches of the Belize River had a maximum turbidity level of 1 NTU. While it is impractical to assign a range of values to turbidity due to the variation in stream types, normal streams have turbidity levels less than 5 NTU (Tunich Nah, 2000). Therefore, it can be concluded that all three reaches of the river had turbidity levels within normal acceptable range. Turbidity is often accompanied by another influencing factor, conductivity.

Table 1 shows that the highest level of conductivity, 3.08 mS/cm was seen in the lower reach. Both the upper and mid reaches had low conductivity levels of around 0.3 mS/cm. This result indicates that there are very few anions (chlorides, nitrates and phosphates) in the water as would be expected in polluted waters (US EPA, 2012). As stated by the US EPA (2012), setting a limit on conductivity is impractical, as the conductivity of a water body does not have a direct effect on the health of that system. Therefore, no conclusive statement can be made about the health of the water solely on the level of conductivity of the water.

LIMITATIONS/ SOURCES OF ERROR

It is possible that the hydrolab sonde was not properly calibrated, which would explain the very low dissolved oxygen levels found even in the very lotic areas of the river. Furthermore, during the surveying of the mid reach of the river, the survey had to be postponed due to engine failure. Prior to engine failure, seven samples were already done. However, the other six samples could not be completed until roughly two weeks later due to lack of access to equipment. The equipments were used by the marine coordinator of the Environmental Research Institute of the University of Belize for a Field Methods course for the Bachelor's Degree course in Natural Resource Management.

CONCLUSION

This study provided valuable information on the water quality of the Belize River. Referring to the self-designed health rating (Table 2), it can be concluded that the overall health of the river is ok. The middle reach appears to be the healthiest of all the three reaches and this may be attributed to the high forestation level within that region. The lower reach had the worst health rating of all three reaches. The concentrations of nitrogen-based elements such as ammonia, nitrates and nitrites were highly elevated, as well as phosphate levels. Dissolved oxygen levels were also far below minimum acceptable limits. This could essentially be the reason for the recent mass mortality of fishes in the lower reach. The upper reach was the mid-health reach whereby it showed elevated levels of nitrogen-based elements, as well as phosphate-based elements. However, the levels were as critically above normal as with the lower reach. Dissolved oxygen showed low concentrations, however, this could be due to equipment malfunction as the area had high turbulence, which would result in greater dissolved oxygen levels. For all three reaches of the river, the possibility of an algal bloom is high, given that the main nutrients necessary, phosphates and nitrates/ammonia, are present in elevated levels (Twomey *et al.,* 2005). It is possible that the factor preventing algal blooms is the fast flow of the river.

RECOMMENDATIONS

Sliva & Williams (2001) noted that urban land use had the greatest influence on water quality. Therefore, given the elevated levels of phosphates, as with the findings of Litke (1999), establishing a ban on phosphate based detergents and chemicals is one possible solution on a domestic scale. However, this cannot be put into place regarding the fertilizers; this is because phosphorus is a key ingredient in plant growth. Nevertheless, ensuring that farmers maintain the buffer (riparian forest) beside the river will ensure less runoff/erosion from hill-slopes and will reduce stream bank erosion (McKegrow *et al.,* 2003) and will also ensure that the turbidity remain as low as it is currently. However, effective restoration of water quality of the river would require the policy makers to focus on riparian zone area and understand the interrelationship of land uses and water quality and thereafter enact regulations to fully protect the riparian forest (Gwayali, Techato, Yuangyai, Musikavong, 2013). For the elevated nitrite level, households can resort to purchasing purifying machines, if economically feasible, or purchase purified water from any of the major purified water producers. This is especially important in cases where consumption by infants is involved as methemoglobinaemia can, and should be prevented. Other treatment methods include biological denitrification, addition of oxidation agents to promote the formation of the more stable nitrate ion as opposed to nitrite ion. These are treatment methods found to be adequate by Health Canada (1987). In terms of the low dissolved oxygen levels, it is recommended that it be re-sampled to correct errors in sampling from this research.

Furthermore, during the survey, it was observed that many areas along the river were being used as easy garbage disposal areas. The garbage can be seen from afar, along the riverbank, and even in the water. Not only is it unhealthy, it is also illegal. Therefore, a survey of the riverbank should be done by the Department of the Environment and all polluters should be charged accordingly. The Department of the Environment should also monitor tributary streams that flow from places of business, especially those that release effluence into the environment. Simply having effluent limitation regulation is not enough.

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APPENDIX

Appendix 1. MRUSF- Summary of Water Quality Data 1. Extracted from AMEC E&C Services Limited EIA for BECOL (2001).

CANADIAN INTERNATIONAL DEVELOPMENT AGENCY
MACAL RIVER UPSTREAM STORAGE FACILITY
ENVIRONMENTAL IMPACT ASSESSMENT – PART 2
Support Documents - Water Quality Analysis Report

TABLE 2.2:
MRUSF - SUMMARY OF WATER QUALITY DATA

Ions and Physical Parameters (Units)	CI Power (1992) (sampling of upstream area only) (from Appendix 2)	Tunich Nah-Consultants (1999) (from Appendix 1)		Criteria	Comments
		Reservoir Area (1999 sampling)	Downstream reservoir (1999 sampling and WASA)		
Alkalinity (mg/l)	27-91	30-96	53-345	30-500 mg/l	Alkalinity is a measure of the water's ability to neutralize acid or its buffering capacity against water acidification. Results for the reservoir area indicate a moderate alkalinity with a range of 27-96 mg/l; at or above peak levels of 90 mg/l in the Raspaculo River to a low of 27 mg/l reported upstream at Kinloch's Camp. General range of this parameter was between 100 and 200 mg/l for ten years of data from WASA. Values of 350 mg/l are still within acceptable range. To protect the natural environment, alkalinity should remain at natural background levels without sudden variations.
Calcium (mg/l)	5.6-26.6	-	-	10-100 (Canadian)	One of the most abundant cations in surface waters is calcium. It is very soluble in water. Its introduction to the aquatic environment comes from the weathering of limestone formations found along the river system. The water samples ranged from 5.65 mg/l at Kinloch's Camp (upstream) to 26.6 mg/l on the Raspaculo River, where limestone was observed on the river banks and in the channels. The calcium values are typical.
Carbonate (mg/l)	Less than 0.7	-	-	<10 (Canadian)	Typically, carbonates are absent from surface waters. In Canadian surface waters, values are generally less than 10 mg/l. Water samples taken in 1991 and 1992 indicated that carbonates were not present in water associated with the study area.
Chloride	6-10	-	-	< 10 (Canadian)	Typical chloride concentrations were between 6 and 10 mg/l. These values are within the expected range from a humid region where values for chloride are generally low, less than 10 mg/l.

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Appendix 2. MRUSF- Summary of Water Quality Data 2. Extracted from AMEC E&C Services Limited EIA for BECOL (2001).

TABLE 2.2:
MRUSF - SUMMARY OF WATER QUALITY DATA

Ions and Physical Parameters (Units)	CI Power (1992) (sampling of upstream area only) (from Appendix 2)	Tunich Nah-Consultants (1999) (from Appendix 1)		Criteria	Comments
		Reservoir Area (1999 sampling)	Downstream reservoir (1999 sampling and WASA)		
Conductivity (u)	82-200	80-133	128-903	-	Conductivity is a numerical value expressing water's ability to conduct an electrical current. In general terms, the concentration and nature of dissolved ions determines the electrical conductivity of the water. Conductivity will vary with the amount of dissolved solids. Conductivity ranged from 82-200 umhos/cm^2 in the area in 1992. Data from Tunich Nah-Consultants (see Appendix 1) indicates higher values from 200 to 800 where human activity is greater in the downstream reaches and because of salinity near the coast.
Colour (TCU)	4-40	18-53	2-300	-	Ten-year curves for Double Run indicate high values because of wetlands and swamps. Belmopan values are also high probably because of human activity. Upstream values are normal and reflect natural conditions.
Hardness (mg/l of $CaCO_3$)	42-82	8-50	72-500	10-100	In most surface waters, the major components contributing to hardness are calcium and magnesium expressed as a calcium carbonate ($CaCO_3$) equivalent. A natural source of hardness is the leaching and weathering of limestone. Water hardness is a modifying factor in the toxicity of many heavy metals. Hardness is used as a means of assessing water quality, but often hardness is also associated with scale deposits on heating systems and the need for excessive use of soap. Upstream hardness ranged from low values upstream to higher values downstream near Guacamallo Bridge, with highest values on the Raspaculo River. There the water is classified as soft to moderately soft. Water hardness increases from San Ignacio to Double Run and ranges from moderately hard to very hard (more than 180 mg/l).

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Appenix 3. MRUSF- Summary of Water Quality Data 3. Extracted from AMEC E&C Services Limited EIA for BECOL (2001).

TABLE 2.2:
MRUSF - SUMMARY OF WATER QUALITY DATA

Ions and Physical Parameters (Units)	CI Power (1992) (sampling of upstream area only) (from Appendix 2)	Tunich Nah-Consultants (1999) (from Appendix 1)		Criteria	Comments
		Reservoir Area (1999 sampling)	Downstream reservoir (1999 sampling and WASA)		
Potassium (mg/l)	Less than 1.5	-	-	<10 mg/l	Potassium values in water samples were generally at values of less than 1.5 mg/l. Typical potassium concentrations in Canadian surface waters are generally less than 10 mg/l.
Magnesium (mg/l)	3.1-5.2	-	-	1-100 (Canadian)	In the upstream area, magnesium concentrations ranged from 3.1 to 5.2 mg/l. These are typical values of natural water sources with magnesium containing rocks. No trend in magnesium values in relation to sampling points was evident.
Sodium (mg/l)	2.8-6.9	-	-	9 mg/l	In the upstream area, water samples showed values for sodium from 4.1-6.9 mg/l with the area to be flooded at 2.8 mg/l. The water samples from the Macal River system are typical in concentration for sodium in surface river waters.
pH (pH)	6.7-8.1	7.6-8.8	6.5-8.5	6-9	Freshwater aquatic guidelines from both Canada and those from the World Health Organization indicate a pH range between 6-9 as acceptable. Water sampling in the watershed showed pH values between 6.7 and 8.9, which are acceptable for the protection of the aquatic environment.
Sulphate	3.7-10	7-12	4-500	-	Sulphate levels are low, except where saline intrusion increases values.
Turbidity (NTU)	1-3.4	0.6-1.33	1-40	1-1000 (runoff)	Turbidity levels in the upstream area are fairly low. Downstream levels are higher because of human activity (agriculture, erosion). Turbidity levels are much higher during the rainy season because of importance of runoff (see curves derived from WASA).

Appendix 4. Sampling results extracted from Tunich Nah Consultants EIA for Belize Electricity Limited (2000) 1.

Table 1. Results of Sampling Program at Eight Stations

Parameter	Date Of Sampling	Monkey Tail [1]	Kenloch [2]	Bailarina Road [3]	Guacamallo Bridge [4]	Christo Rey village [5]	Spanish Lookout bridge [6]	Guanacaste Park (Belmopan) [7]	Burrel Boom Bridge [8]
Alkalinity (mg/L)	April, 23	96	29	53	53	77	146	168	150
Alkalinity (mg/L)	April, 28	30	32	58	55	98	143	232	154
Chlorides (mg/L)	April, 23	17	13	12	12	13	11	11	50
Chlorides (mg/L)	April, 28	16	16	13	12	18	16	13	63
Salinity (ppt)	April, 23	0	0	0	0	0	0.1	0.1	0.4
Salinity (ppt)	April, 28	0	0	0	0	0	0.1	0.2	0.4
Colour (units)	April, 23	33	18	20	17	14	20	13	34
Colour (units)	April, 28	53	31	19	89	18	2	13	40
Hardness, Total	April, 23	39	36	54	63	88	170	195	415
Hardness, Total	April, 28	36	36	62	62	117	180	253	468
Hardness, Ca.	April, 23	23	22	42	47	72	136	164	337
Hardness, Ca.	April, 28	22	28	50	49	112	142	214	399
Hardness, Mg.	April, 23	16	14	12	16	16	34	31	78

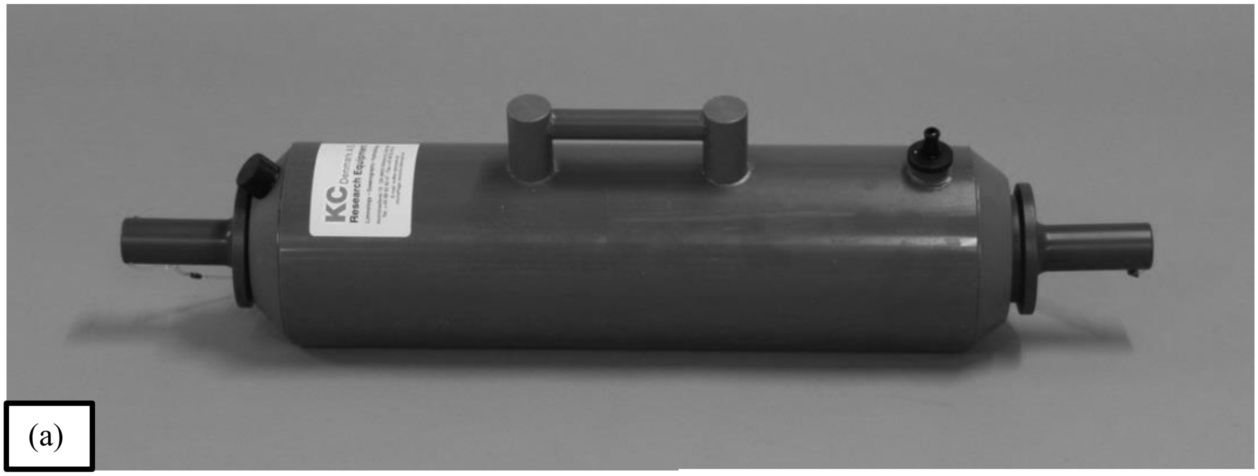
Appendix 5. Sampling results extracted from Tunich Nah Consultants EIA for Belize Electricity Limited (2000) 2.

Hardness, Mg	April, 28	14	8	12	13	5	38	39	69
Iron (mg/L)	April, 23	0.09	0.13	0.09	0.1	0.1	0.04	0.03	0.03
Iron (mg/L)	April, 28	0.1	0.16	0.09	0.02	0.07	0.03	0.08	0.05
TDS (mg/L)	April, 23	45.8	40	62	65	91	157	176	405
TDS (mg/L)	April, 28	42.1	43.2	66.9	64	117	163	226	451
Sulphate (mg/L)	April, 23	7	8	8	4	15	20	20	280
Sulphate (mg/L)	April, 28	12	9	8	11	23	28	6	320
Turbidity (NTU)	April, 23	0.63	0.8	1.33	0.96	1.69	3.28	1.64	3.4
Turbidity (NTU)	April, 28	1.19	0.8	0.89	0.92	1.28	2.7	1.8	2.6
pH	April, 23	7.61	8.05	8.09	8.13	7.89	8.14	8.01	8.05
pH	April, 28	8.3	8.77	8.8	8.89	8.59	8.76	8.3	8.74
Nitrate (mg/L)	April, 23	0.2	0.4	0.4	0.3	0.7	0.7	1	0.6
Nitrate (mg/L)	April, 28	0.6	0.5	0.7	0.4	1	0.2	1	0.6
D.O. (mg/L)	April, 23	5.2	5	5	5.2	4.8	5.2	5.2	5.2
D.O. (mg/L)	April, 28	5	5.4	5.6	5.2	5.4	5.6	5.4	5.6
Temp. degree C	April, 23	21	19.4	22.7	18.8	19.8	20.9	19.5	20.4
Temp. degree C	April, 28	23.1	22.1	21.8	22.9	21.8	21.9	21.4	22
Cond. (umhos/cm)	April, 23	91.6	80	124	130	182	315	353	811
Cond. (umhos/cm)	April, 28	84.2	86.5	133.9	128.1	235	327	452	903

Appendix 6. Sample data sheet from Hydrolab Sonde (excluding Sample #).

Upper Reach Surface										
Date / Time	Temp [°C]	pH [Units]	SpCond [m	Sal [ppt]	DO [mg/l]	NH4+ [mg/l-N]	Turbidity [Rev]	Nitrate (NO3--N)	Nitrite (NO2-)	Phophate (PO4-3)
5/27/13 11:49	28	8.62	0.3	0.12	1.23	7.58	0	1.6	3	0.51
5/27/13 12:10	28.01	8.71	0.3	0.14	1.35	7.63	1	1.3	2	0.42
5/27/13 12:29	28.08	8.69	0.3	0.13	1.83	8.14	1	1.4	2	0.46
5/27/13 12:49	28.27	8.73	0.3	0.13	1.43	8.63	1	1.5	2	0.31
5/27/13 13:10	28.37	8.75	0.3	0.13	1.32	8.74	1	1.4	3	0.35
5/27/13 13:28	28.37	8.72	0.3	0.12	1.17	8.17	0	1.3	2	0.35
5/27/13 13:45	28.49	8.72	0.3	0.13	0.88	8.86	1	1.3	2	0.37
5/27/13 14:25	28.64	8.77	0.3	0.13	1.57	8.13	1	1.6	6	0.36
5/27/13 14:45	28.73	8.81	0.3	0.14	1.01	8.33	0	1.4	7	0.38
5/27/13 15:03	28.77	8.81	0.3	0.14	1.41	8.78	1	1.6	6	0.36
5/27/13 15:20	28.6	8.86	0.3	0.13	1.23	7.64	0	1.6	7	0.37
5/27/13 15:37	28.64	8.9	0.3	0.13	1.75	7.46	1	1.7	7	0.35
5/27/13 16:01	28.57	8.82	0.3	0.13	1.13	7.92	0	2	7	0.31

Appendix 7. (a) Niskin Water Sampler, (b) Hach Hydrolab Sonde, (c) Garmin GPS.



(a)

(b)

(c)

Appendix 8. Photos showing riparian deforestation by burning.