Effect of non-point source runoff and urban sewage on Yaque del Norte River in Dominican Republic

Peter Phillips*

Department of Biology, Winthrop University,
Rock Hill, South Carolina 29733, USA
Fax: 803 323 3448 E-mail: phillipsp@winthrop.edu
*Corresponding author

F. Arturo Russell

Pontificia Universidad Católica Madre y Maestra,
Santiago de los Caballeros, República Dominicana
Fax: 809 582 2947 E-mail: arussell@pucmmsti.edu.do

John Turner

Department of Biology, Winthrop University,
Rock Hill, South Carolina 29733, USA
Fax: 803 323 3448 E-mail: turnerj2@winthrop.edu

Abstract: A Yaque del Norte, Dominican Republic watershed survey monitored dissolved oxygen, eutrophication from point and non-point sources, and high conductivity resulting from agricultural runoff. The upper mainly forested watershed had good water quality except for untreated sewage from the city of Jarabacoa. The mid-watershed had a deforested landscape, mixed agriculture and the city of Santiago contributing nitrogen and phosphorus. The lower watershed had extensively-irrigated agriculture resulting in appreciably higher conductivity, as well as high nitrogen and phosphorus. Sedimentation from erosion is evident throughout the watershed. Managing the river's land and water resources for all stakeholders is critical.

Keywords: surface water quality; nitrogen; phosphorus; dissolved oxygen; turbidity; non-point source runoff; point sources; irrigation; Yaque del Norte River; Dominican Republic.

Reference to this paper should be made as follows: Phillips, P., Russell, F.A. and Turner, J. (2007) 'Effect of non-point source runoff and urban sewage on Yaque del Norte River in Dominican Republic', *Int. J. Environment and Pollution*, Vol. 31, Nos. 3/4, pp.244–266.

Biographical notes: P. Phillips is an Associate Professor of Biology in the Department of Biology, Winthrop University, Rock Hill, South Carolina, USA, since 1999. He conducts water quality research on the Catawba River basin in North and South Carolina. He was the recipient of a Fulbright Scholar Award in the summer of 2004; this funded the research effort in the Dominican Republic. He was previously a Research Scientist at Clark Atlanta University, Atlanta, Georgia, USA, conducting research on bioremediation of contaminated water using a microbial mat based technology.

F.A. Russell is a Professor of Biology and Ecology in the Natural Sciences Department, Pontificia Universidad Católica Madre y Maestra, Santiago, Dominican Republic.

J. Turner is a Biology student (graduated December 2004), Department of Biology, Winthrop University, Rock Hill, South Carolina, USA.

1 Introduction

In much of the world, there is a severe imbalance between freshwater supply, human consumption and population (Jackson et al., 2001). In the Dominican Republic (DR), per capita water availability is approximately 1,500 m^3 per capita/year, the surface water supply is 20×10^9 m^3/year and the groundwater supply is 1.5×10^9 m^3/year. Extensive irrigation and high consumption in urban areas uses 10×10^9 m^3/year, or 47% of total supply. In some regions of the country, there is a water scarcity problem as a result of poor management of irrigation, urban water supplies and tourist infrastructure. The Dominican Hydraulic Resources Institute (INDRHI) projects a future water deficit in the Yaque del Norte River (Banco Mundial, 2004), site of the current study.

Compounding the issue of water availability and consumption is the contamination of water supplies due to non-point source runoff and the lack of wastewater treatment facilities. The impact of this problem in DR's largest watershed was the subject of this research.

1.1 Water quality and wastewater treatment in DR

There is a need for systematic monitoring of water quality in DR (Banco Mundial, 2004). The general lack of proper handling of waste has contaminated water sources and caused disease. Coastal water quality also is greatly affected by water pollution inland.

Nationwide, 94% of urban and 65% of rural population has water supplied by pipes, for a national mean of 84%. More than 50% of homes have no plumbing and residents must walk to a public water supply. Only 58% of aqueducts carried chlorinated water in 1998. In the same year, in National Potable Water and Drainage Institute (INAPA) aqueducts supplying 40% of the population with water, the proportion of water samples with coliform bacteria rose from 17% in 1994 to 23% in 1998 (Banco Mundial, 2004).

In the Yaque del Norte River watershed, there are 21 potable water treatment plants, 35% of these control water quality by lab analysis and only Santiago's water system (second-largest DR city) met quality control in 1998. Water quality degrades appreciably along the lower Yaque del Norte River watershed (Abt Associates, Inc., 2002).

Watershed management requires the collaboration of farmers, forestry agents, municipalities, industry, tourism operators, garbage collection entities and civil society. Nationally, 89% of the population has some type of sanitary connection, but only 20% is connected to centralised wastewater systems. In Santiago, 86% of its population is connected to a sewer system, treating 94% of wastewater. However, a considerable quantity of raw wastewater still enters the Yaque del Norte River. Jarabacoa, a mountain city of approximately 50,000, has no wastewater treatment (Rodríguez Taveras, 2000).

Nationwide, less than 10% of industrial effluent is treated. In Santiago, estimates are that 200 industrial discharges into Yaque del Norte have the equivalent impact of 1,000,000 inhabitants (Consejo para el Desarrollo Estratégico de la Ciudad y el Municipio de Santiago, Inc., 2002).

The Yaque del Norte River is contaminated by municipal wastes, industries, hog farms, poultry farms, slaughterhouses and non-point sources of runoff and dumping by inhabitants all along the river's length (Rodríguez Taveras, 2000). Previously, Hartshorn et al. (1981) has characterised it as having water of poor quality with a high content of suspended solids and microbial contaminants. Banco Mundial (2004) reported that in Yaque del Norte and nearby Yuma watersheds, livestock contributes 20% of its biochemical oxygen demand (BOD). In 2000, BOD input into the Yaque del Norte River was due to liquid effluents (45%), urban runoff (1%), industrial effluent (6%), livestock (22%) and solid waste (26%). However, since only one-third of the cost of treating wastewater is covered by utility charges, there is little capital for infrastructure investment (Banco Mundial, 2004).

High salinity and pesticides are also serious problems near agricultural, urban and industrial areas. INDRHI's water quality laboratory is equipped for physical, chemical and bacteriological analyses of water, and is potentially capable of handling 4,800 samples/year. However, due to lack of personnel and financing, the use of this monitoring lab has diminished considerably since 1994 (Banco Mundial, 2004).

1.2 Environmental protection in DR

In 2003, the Dominican Secretariat of Environment and Natural Resources (SEMARN) established water quality regulations for DR. It defines primary and secondary human contact with water. Class A can be used as a public water supply after simple disinfection, for direct contact recreation, for example swimming, or for irrigation on crops that will be consumed raw. Class A waters are meant to preserve fauna and flora. Class B waters can be used as a public water supply after treatment, used in recreation without direct contact, for example fishing, or for irrigation and industry. Regulations on dumping a great variety of chemicals and other wastes into receiving water bodies are also contemplated in SEMARN (2003). Based on these categories, the Yaque del Norte River would fit within Class A or B.

Environmental management in DR is needed to guarantee sustainable growth, especially in the tourist sector, and to minimise the impact that environmental degradation has on the poor. For example, in terms of water management and Dominicans who lack access to a public water supply, potable water may cost 40 times more than if they were provided with a potable water system. As an outcome of a non-existent or deficient and expensive potable water supply system, diarrhea and severe respiratory infections are, respectively, the first and third causes of death in children less than five years old (Banco Mundial, 2004).

Floods and other natural disasters are notable in DR. During the 1990s, floods were the most frequent natural disaster. In 1998 Hurricane Georges caused US$ 2.2 billion damage, 235 deaths and the loss of land and infrastructure on the coast, reduced tourist and fishery products income and agricultural production.

By 2003 water quality and solid waste management were considered the most urgent environmental challenges, followed by water scarcity and watershed and soil degradation. Banco Mundial (2004) recommended supporting SEMARN to cultivate the practice of environmental conservation among the Dominican public. SEMARN has the potential to play a leadership role in catalysing the socialisation of environmental themes. It has a department charged with offering environmental education to school teachers throughout the country as well as producing didactic materials on environmental education. Specifically, in relation to the Yaque del Norte River, SEMARN is in negotiation to reach an agreement with an electrical corporation to provide environmental services in the watershed. The same Banco Mundial (2004) document recommended a series of pilot studies on Yaque del Norte sub-watersheds in the area of Santiago, since this community has demonstrated its capacity for planning, as demonstrated by its detailed environmental plan.

1.3 Current study

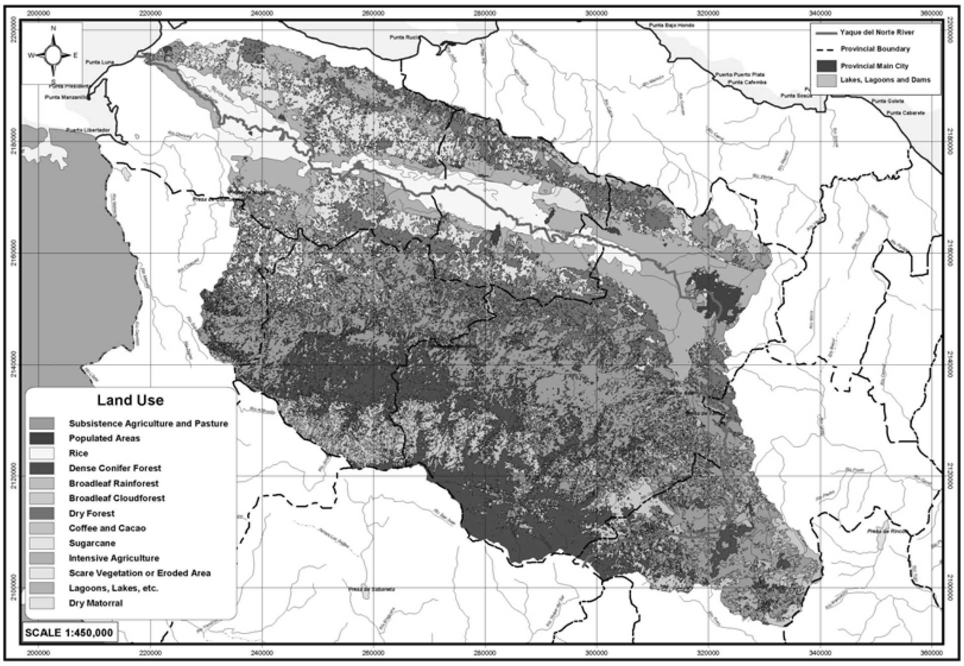
In this assessment of Yaque del Norte River basin water quality, sampling sites along the river included near pristine habitats in the river's headwaters, areas impacted from non-point sources of sediment and nutrient run-off as well as wastewater discharge points from cities and industries. The intent of this survey was to establish an updated baseline of data on the condition of Yaque del Norte River water quality to assist managers and planners in judging and addressing the impact of nutrient addition, raw urban wastewater input and agricultural runoff into this largest of DR watersheds for future management of the aquatic resource. This will achieve a balance between agricultural irrigation, potable water supply, wastewater treatment, tourism development and ecosystem health needs.

2 Yaque del Norte River watershed

2.1 Land use in the Yaque del Norte River watershed

The northern Yaque del Norte River valley area is geologically young. Loamy, moderately alkaline, fertile topsoil is very productive with irrigation. Slopes on either side of the valley, lined by the Central Cordillera and the Northern Cordillera, have poorer soils (Bolay, 1997). In Figure 1, the land use map shows that highest elevations of the upper watershed consist of dense conifer, diverse broadleaf humid or cloud forest, much of which are protected lands within the José Armando Bermúdez National Park. Outside of park boundaries, almost all remaining land in the watershed has been altered by humans. In the Central and Northern Cordillera foothills, most land is dedicated to subsistence agriculture and pasture. Frequently, areas on steep inclines have been severely eroded and abandoned. The upper watershed contains the mountain city of Jarabacoa. The largest city on the river is Santiago, at 200 metres elevation and approximately mid-way along the river course to the ocean. In the western half of the lower watershed, annual precipitation declines significantly. In these arid regions, dry forest, or mattoral, dominates in areas that lack occupation by human settlement and agriculture. The entire watershed human population was 1,245,685 in 2000, with approximately 800,000 living in Santiago. Within Santiago, an estimated 75,000 to 100,000 inhabit stream ravines, or arroyos, in settlements lacking wastewater treatment and subject to periodic flooding (Abt Associates, Inc., 2002).

Figure 1 Land use in the Yaque del Norte River watershed, northwest Dominican Republic



2.2 *Shifting cultivation and deforestation*

The Dominican Republic's forest cover declined from 70% in 1940 to approximately 25% at present. Slash-and-burn agriculture, or shifting cultivation, is one of the principal factors in deforestation and environmental degradation. It has occurred mainly at low and medium elevations of the Yaque del Norte watershed. This practice occurs on small parcels; fields are used for one to two years, soil nutrients are exhausted and then abandoned with inhabitants moving to a new parcel. If left for 10–20 years, soil fertility may be restored. However, under current use patterns, land is used too intensively for recovery. Additionally, cattle grazing on fallow land leads to overgrazing. A farmer eventually has to cultivate clayey subsoil with less than 1% organic content, subject to water-logging. This eventually leaves land useless for agriculture (Bolay, 1997).

In the western Yaque del Norte watershed, only 3% of land is suitable for intensive agriculture, 16% for marginal agriculture, 28% for cattle and 53% for forestry. However, in 1980, 20.9% of the land was used for intensive agriculture, 30% for marginal agriculture, 37% for natural grassland and 10% for forestry. This land use has led to reduced productivity (Bolay, 1997).

At higher elevations, shifting cultivation has been practised during, approximately, the past 30 years; so degradation is not as severe and some forest cover is left. These are acidic soils with a lower nutrient content and are more likely to be used for cattle grazing and coffee cultivation (Bolay, 1997).

2.3 River volume, impoundments and sedimentation

Rainfall infiltration rates are affected by loss of forest and soil. Normal erosion for subtropical environments ranges between 0.4 to 1.8 tons/ha/year. Ninety percent of Central Cordillera soils are affected by erosion. The Yaque del Norte River watershed has been losing topsoil at a rate of 275 tons/ha/year. One of the subwatersheds, the Guayubín River, has lost topsoil at a rate of 111 tons/ha/year. It has been suggested that with such high soil loss, future reforestation efforts may be impossible (Bolay, 1997).

Hartshorn et al. (1981) noted that rivers are dammed with little thought for deforestation and agricultural uses of the land, in terms of erosion and sediment. The Yaque del Norte River watershed has three major dams: the Taveras Dam and Bao-López Dam Complex are both located in the mid-watershed, upstream from Santiago on the Yaque del North and Bao Rivers. The Monción Dam is located on the Mao River in the lower watershed (Rodríguez Taveras, 2000). Before dam construction began, the Yaque del Norte River flow rate was estimated to range between 38 m^3/second and 100 m^3/second (Rodríguez Taveras, 2000), with a median flow of 64 m^3/second. The flow rates of the Mao and Guayubín Rivers are 25.12 m^3/second and 13.38 m^3/second (Bolay, 1997; Hartshorn et al., 1981). Highest flow rates occur in May, August, September and November.

The major problem presented by deforestation is sedimentation in reservoirs and irrigation canals. The Yaque del Norte watershed reservoirs operate with an approximate rate of efficiency of 40%. Efficiency is even lower regarding uses for human consumption and irrigation. In 1978, the Taveras Reservoir had a sedimentation rate of 1,300 m^3/km^2/year. In 1981, the rate was estimated at 2,500 m^3/km^2/year. In 1993, INDRHI estimated a 20-year average sedimentation rate of 1,800 m^3/km^2/year. By 2022, sediment levels will reach the point where water is removed for hydroelectric generation and the reservoir will be 50% filled in (Rodríguez Taveras, 2000).

In terms of erosion and flooding, weak watershed management has led to soil erosion and has amplified the quantity and frequency of flood damage. Surface water runoff is responsible for most river flow and, as an example, the Guayubín River reportedly rises one to 10 metres within a few hours after rain. Then its volume rapidly diminishes (Bolay, 1997).

2.4 Runoff and irrigation

The Yaque del Norte, including its many tributaries, is the most utilised river in DR in terms of irrigation canals (Núñez Molina, 1987). Bolay (1997) discusses problems in the western portion of the watershed due to salinisation, water-logging and water contamination from agrochemicals or wastewaters. Sedimentation from erosion and runoff also greatly affects irrigation canals (Bolay, 1997).

The initial interest in irrigation was to promote rice cultivation in the 1920s. From that time to the 1980s, 377 km of primary canals and 352 km of secondary canals have been constructed, principally in the mid- and lower watershed region, and irrigate approximately 75,000 ha (Rodríguez Taveras, 2000). Irrigation canals have diverted much of the mid- and lower river volume. Irrigation has led to intensive agriculture, dominated by sugarcane, plantain, cattle and mixed crops. Nationally, irrigation efficiency is 18–25% and farmers do not pay for the real economic value of water (Banco Mundial, 2004).

Salinisation of land and increased conductivity in water is tied to deficient drainage of agricultural lands. A two-month study by INDRHI and GTZ (1993) documented increasing salt content and turbidity downstream from Navarrete, below Santiago. Rodríguez Taveras (2000) also reported that the problem worsens in the western watershed nearing the discharge into the Atlantic Ocean. Estimates are that 31,250 ha in the Yaque del Norte watershed are affected by salinisation and INDRHI estimates that nationally 34% of irrigated lands are affected by salinisation. Rice cultivation has created most of the salinisation problem and substitutes are now being encouraged, including banana, plantain, cashew, melon, sorghum, tomato, corn, pigeon peas, tamarind and grapefruit (Banco Mundial, 2004; Rodríguez Taveras, 2000).

The Yaque del Norte River discharges into the Montecristi National Park. This is a subtropical dry forest, including over 4,000 ha primarily of red mangrove, *Rhizophora mangle*. This region represents the largest DR mangrove forest. Inland from mangroves are saltbeds of halophytic savannah vegetation. Alluvial soils are abundant. Coastal mangroves are protected seaward by coral reefs. Marine turtles, manatees and crocodiles are reported in this area (Bolay, 1997).

3 Materials and methods

3.1 Location of sampling sites and area description

The Yaque del Norte River originates in the Central Cordillera of western Dominican Republic and, after arcing to the east and north, flows northwesterly discharging into the Atlantic Ocean near the Haitian border. The northern boundary of the watershed is enclosed by the Northern Cordillera, a lower ridge of mountains near the north Atlantic coast. The river is located between latitudes 19° 49′ 49″ and 19° 04′ 45″ north (UTM 19Q 0222539 – 0307764) and longitudes 70° 49′ 63″ and 71° 38’ 93″ west (UTM 19Q 2110056 – 2194267) (Figure 2). The total watershed covers a land area greater than 7,000 km^2, or 14% of Dominican territory, at elevations ranging from approximately 3,000 metres to sea level (Bolay, 1997; Rodríguez Taveras, 2000).

A total of 14 sites were sampled up to five times from June to August 2004. Nine sampling sites were established along approximately 200 km of the 308 km river mainstream (Bolay, 1997) from near the boundary of José Armando Bermúdez National Park to near the discharge at Montecristi. Sampling site elevations ranged from 900 m to near sea level. Additionally, a site was established in the Arroyo Hierba Buena canal, carrying raw wastewater from the mountain city of Jarabacoa, the principal montane tourist centre of DR, to the river. Another similar site, Arroyo Nibaje, was established within the city of Santiago. In the lower Yaque del Norte watershed, sites were established near the point where three significant tributaries, Amina, Mao and Guayubín Rivers, discharge in the river mainstream (Table 1).

In the upper watershed, precipitation ranges up to 2,000 mm/year (Hartshorn et al., 1981); normal annual rainfall at Jarabacoa is 1435 mm. In the mid-watershed, normal annual rainfall at Santiago is 1021 mm. The southern areas of the watershed receive adequate rainfall for agriculture without irrigation (Rodríguez Taveras, 2000). The mid-watershed, representing approximately 75% of its land area, is 80% deforested (Rodríguez Taveras, 2000). The lower watershed is characterised by agriculture, irrigation and increasingly arid conditions because Atlantic trade winds are blocked by the Northern Cordillera. Precipitation nearest the coast (Montecristi) averages 675 mm/year (Bolay, 1997).

Figure 2 Fourteen sampling sites were established along approximately 200 km of river and tributaries

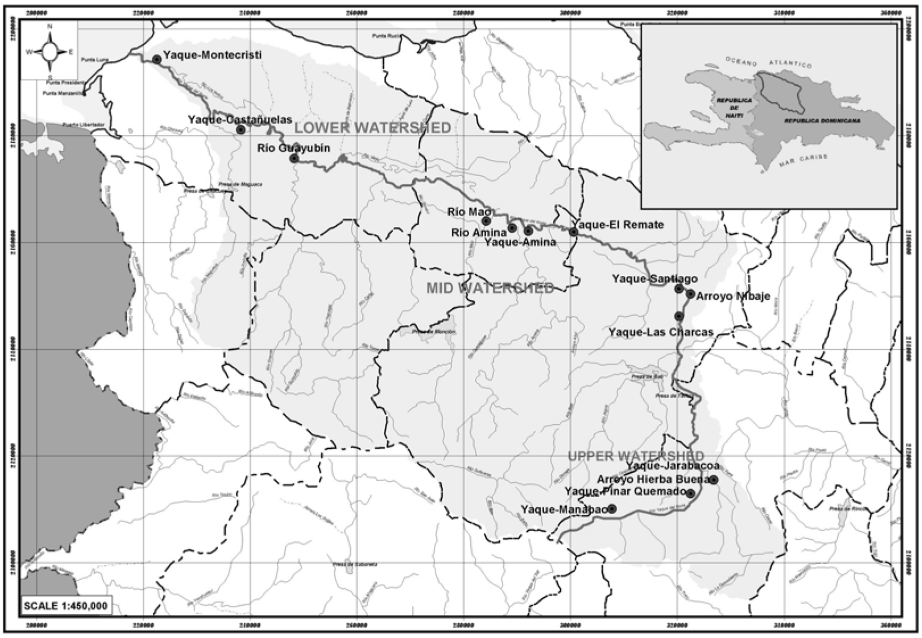


Table 1 Number (*N*) and sampling period for 14 sampling sites in Yaque del Norte River watershed in Dominican Republic

Sampling site	*N*	*Sampling period*
Yaque-Manabao	5	14th June–09th August, 2004
Yaque-Pinar Quemado	5	14th June–09th August, 2004
Arroyo Hierba Buena	3	12th July–09th August, 2004
Yaque-Jarabacoa	5	14th June–09th August, 2004
Yaque-Las Charcas	5	13th June–10th August, 2004
Arroyo Nibaje	4	28th June–10th August, 2004
Yaque-Santiago	5	13th June–10th August, 2004
Yaque-El Remate	5	12th June–11th August, 2004
Yaque-Amina	5	13th June–11th August, 2004
Río Amina	5	13th June–11th August, 2004
Río Mao	5	13th June–11th August, 2004
Río Guayubín	5	13th June–11th August, 2004
Yaque-Castañuelas	5	13th June–11th August, 2004
Yaque-Montecristi	4	29th June–11th August, 2004

3.2 Sampling procedure

Temperature, dissolved oxygen, pH, conductivity and turbidity were measured in situ with a Horiba U-10 Water Quality Checker and a YSI Model 58 Dissolved Oxygen Meter. Ammonia was determined with a Hach Surface Water Kit 25598-00. Additional water samples were collected, frozen and transported to Winthrop University, South Carolina, USA for analysis of total phosphorus, phosphate, total nitrogen and nitrate by a Hach DR/4000 spectrophotometer after appropriate sample preparation. Specific Hach procedures included nitrate by the UV direct reading method 10049, TN by the persulfate digestion method 10071, TP by acid persulfate digestion method 8190 and reactive phosphorus by the molybdovanadate method 8114.

Data quality was assured as much as feasible under Dominican Republic field conditions. Temperature data were collected with two meters for comparison purposes. Prior to each sampling event, the YSI meter was air calibrated for dissolved oxygen measurements. The Horiba meter was likewise calibrated with Horiba AutoCal Solution. The Hach Surface Water Kit was used in accordance with Hach specifications. Water samples collected for analysis at Winthrop University were maintained on ice in the field, then frozen until analysis.

4 Results

Regular heavy precipitation was experienced during initial sampling in May 2004. Precipitation decreased over the course of the study period until completion in August 2004. River volumes, or flow rates, and turbidity fluctuated widely during the entire study period due to frequent precipitation at higher elevations of the watershed.

4.1 Oxygen

In the Yaque del Norte River, mean dissolved oxygen (DO) was always greater than 5 mg/l, in the generally accepted level for sustaining aquatic animal life (Figures 3 and 4). However during several individual sampling episodes downstream from Santiago, DO readings were between 3 mg/l and 4 mg/l during periods of low river volume (Yaque-El Remate site). Additionally, DO in Arroyos Hierba Buena (mean of 4.7) and Nibaje (mean of 1.5) were inadequate. Highest mean DO was found in the lower watershed tributaries of the Amina and Mao Rivers and in upper watershed sites.

4.2 pH

Hydrogen ion concentrations (pH) were consistently near seven throughout the watershed, including the two tributaries conducting raw sewage into the Yaque del Norte River (Figure 5). These values fall within the water quality regulations set by SEMARN (2003).

Figure 3 Mean dissolved oxygen from June to August 2004. The dashed line at 5 mg/l indicates DO levels needed to sustain aquatic life. Circled bars are tributaries

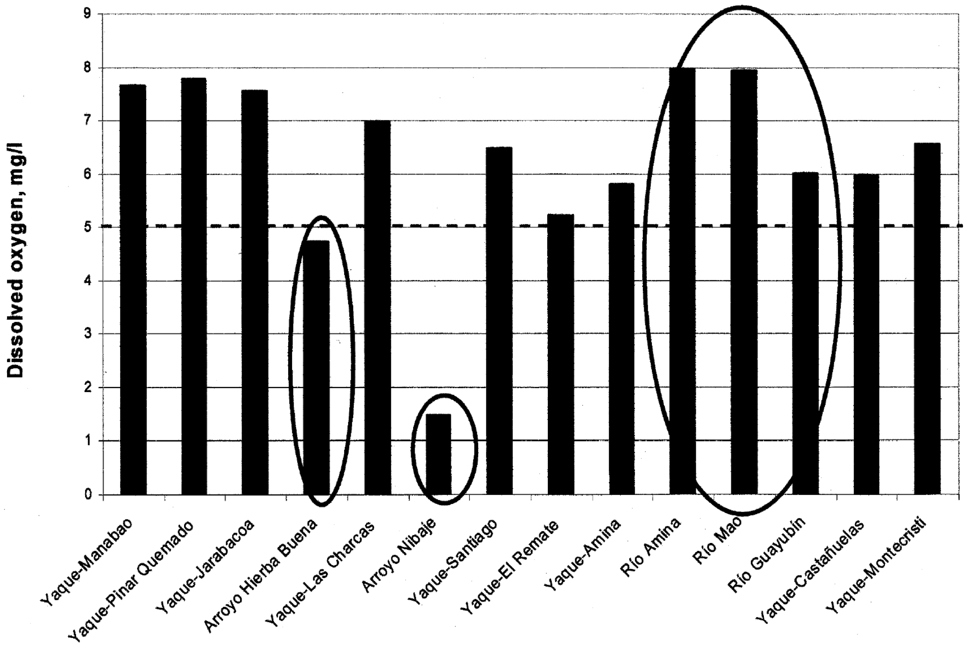


Figure 4 Mean dissolved oxygen from June to August 2004

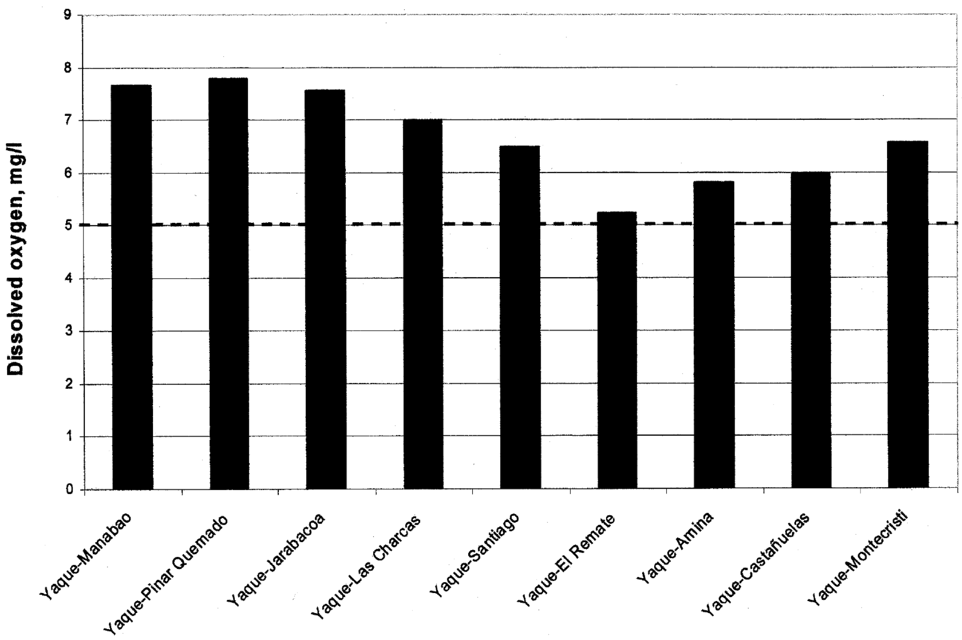
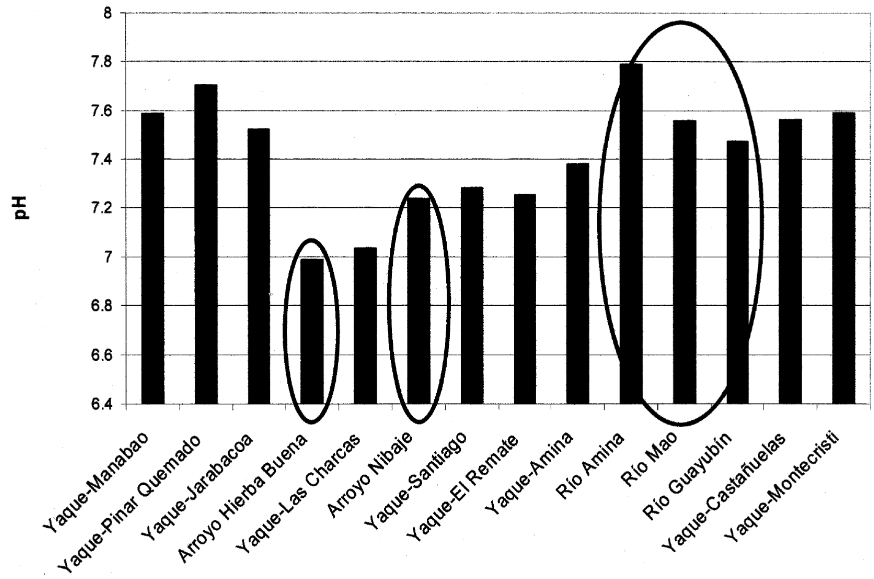


Figure 5 Mean pH from June to August 2004. Circled bars are tributaries



4.3 Conductivity

Mean electrical conductivity was lowest in the high watershed and upper reaches of the mid-watershed, ranging from 0.08 mS/cm to 0.19 mS/cm. Mean conductivity in Arroyos Hierba Buena and Nibaje was significantly higher (0.24 mS/cm and 0.72 mS/cm, respectively) than mainstream river waters (Figures 6 and 7). Downstream of Santiago, conductivity increased substantially to a high mean of 1.05 mS/cm.

Figure 6 Mean conductivity from June to August 2004. Circled bars are tributaries

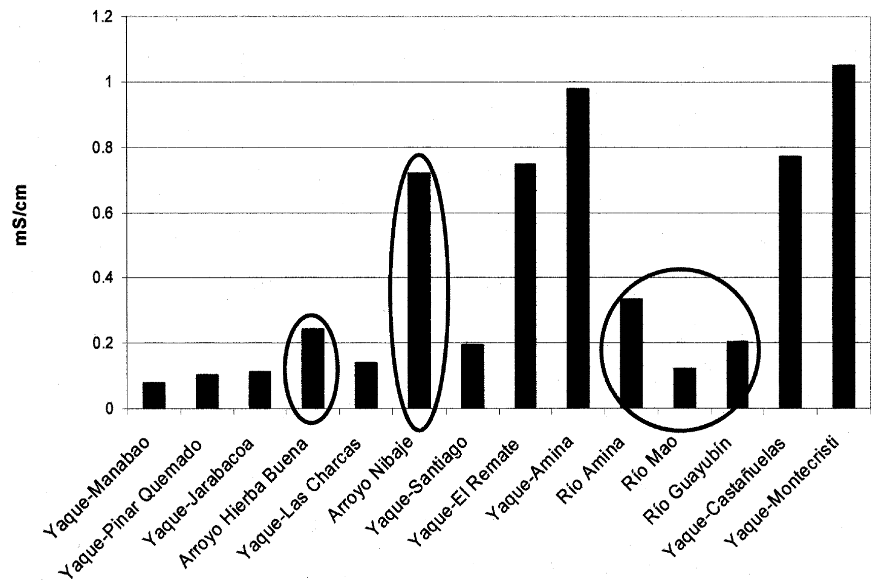
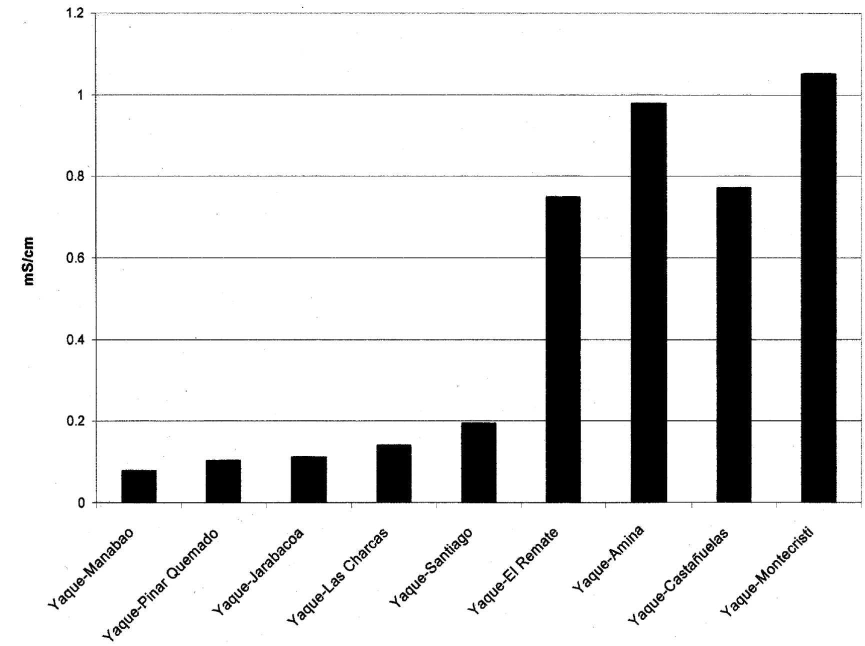


Figure 7 Mean conductivity from June to August 2004



4.4 Turbidity

INDHRI and GTZ (1993) indicate a standard of 100 NTU for DR. Mean turbidity only exceeded this standard in the mainstream of the river below Santiago at Yaque-El Remate and in the Guayubín River (Figures 8 and 9). Upper watershed sites showed low turbidity at all times. Lower watershed sites showed consistently higher NTU readings.

Figure 8 Mean turbidity from June to August 2004. The dashed line at 100 NTU is a standard indicated in INDRHI and GTZ (1993). Circled bars are tributaries

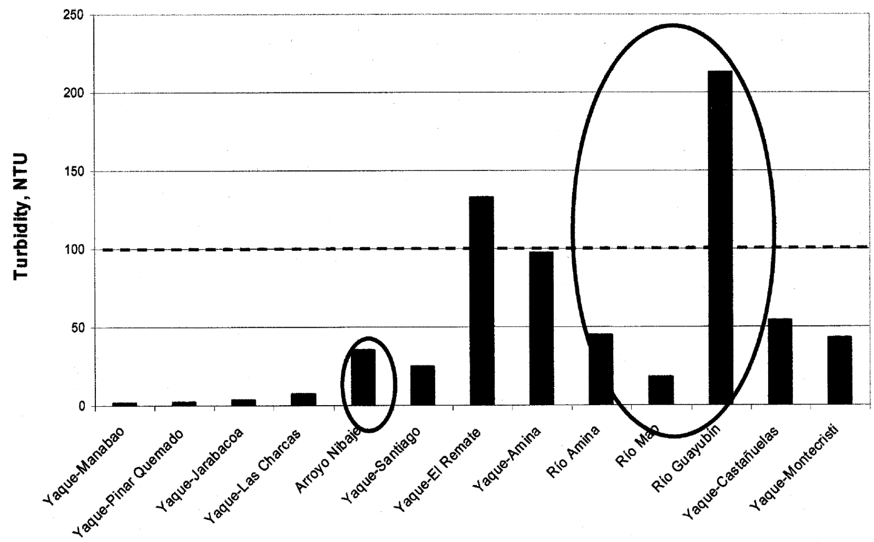
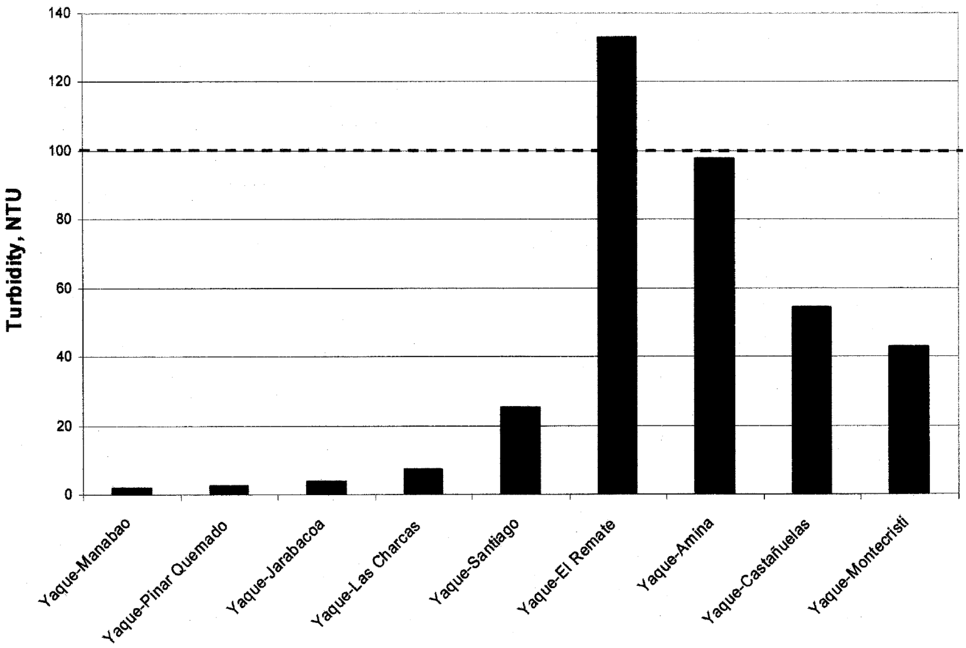


Figure 9 Mean turbidity from June to August 2004



4.5 Nitrogen

Mean TN generally was below 1.5 mg/l, the common US standard employed in this study as a reference point. Arroyo Nibaje, a major source of untreated sewage in Santiago, showed mean TN of 6.3 mg/l and likely had a major impact on mean TN values of 4.2 mg/l in the mainstream of the Yaque del Norte in the centre of Santiago (Figures 10 and 11). Greatest mean nitrate concentrations were found in Arroyo Hierba Buena, conducting raw sewage from the city of Jarabacoa into the Yaque del Norte River (Figure 12). Figures 12 and 13 illustrate high nitrate concentrations throughout in the mid- and lower watershed, peaking in the mainstream at Yaque–Amina. Greatest mean ammonia concentrations were found in Arroyos Hierba Buena and Nibaje, due to raw sewage input from Jarabacoa and Santiago (Figure 14). Measurable amounts of ammonia were detected only in the mainstream of the Yaque del Norte in the centre of Santiago and at the first site downstream from Santiago (Yaque-El Remate).

4.6 Phosphorus

In the current study, significant point source inputs of phosphorus (TP and phosphate) into the Yaque del Norte River emanated from Arroyos Hierba Buena and Nibaje, both conducting raw sewage to the river. Mean TP consistently exceeded 0.025 mg/l, the DR water quality standard set by SEMARN (2003) (Figures 15–18). In the mainstream of the river, both TP and phosphate peak downstream of Santiago at Yaque-El Remate.

Figure 10 Mean total nitrogen from June to August 2004. The dashed line at 1.5 mg/l is a common US standard not to be exceeded and is employed here as a point of reference. Circled bars are tributaries

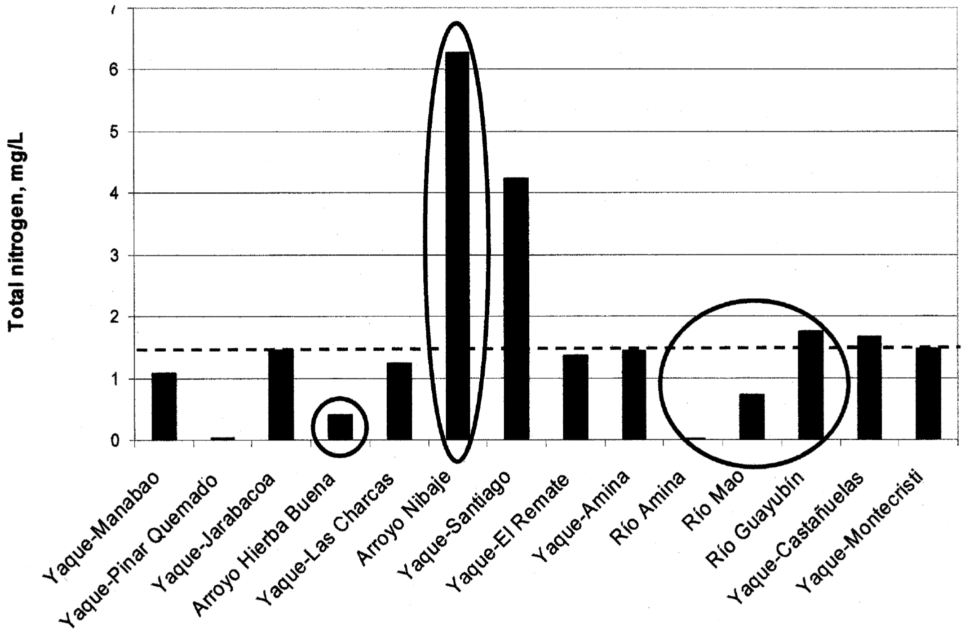


Figure 11 Mean total nitrogen from June to August 2004

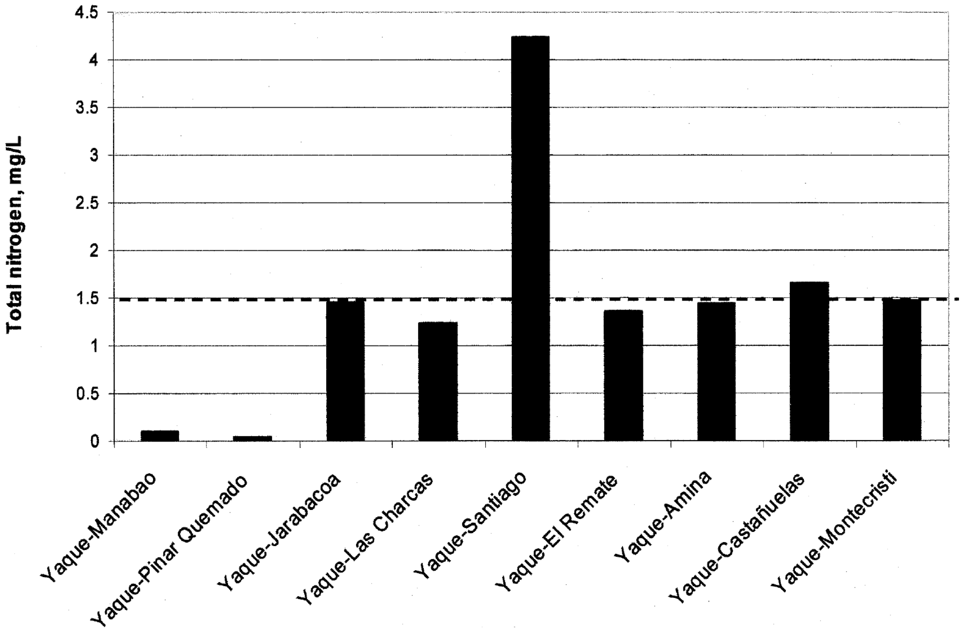


Figure 12 Mean nitrate from June to August 2004. Circled bars are tributaries

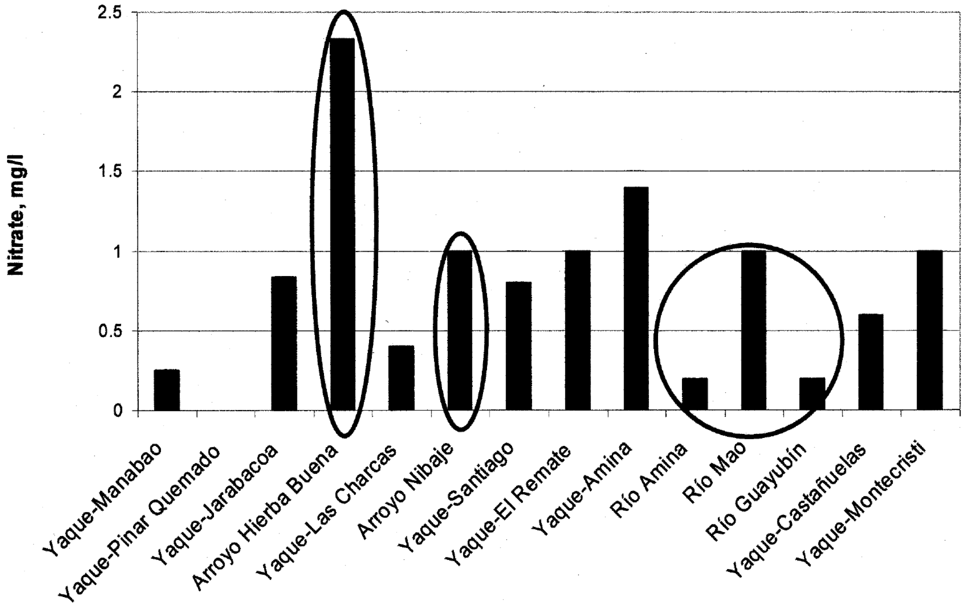


Figure 13 Mean nitrate from June to August 2004

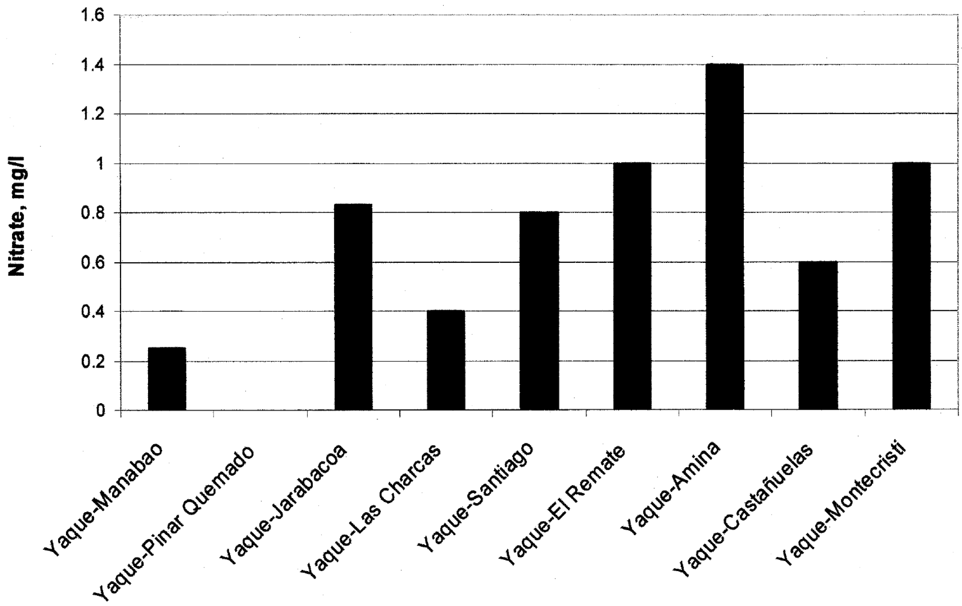


Figure 14 Mean ammonia concentration from June to August 2004

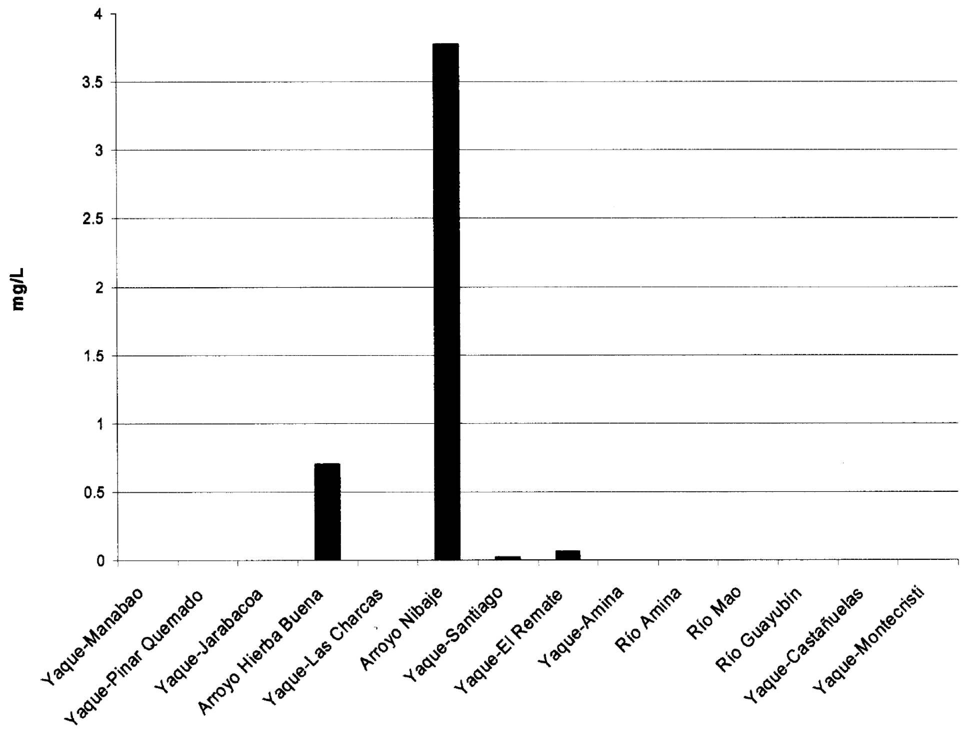


Figure 15 Mean total phosphorus from June to August 2004. The dashed line at 0.025 mg/l is the standard not to be exceeded and is set by the Dominican Secretariat of Environment and Natural Resources. Circled bars are tributaries

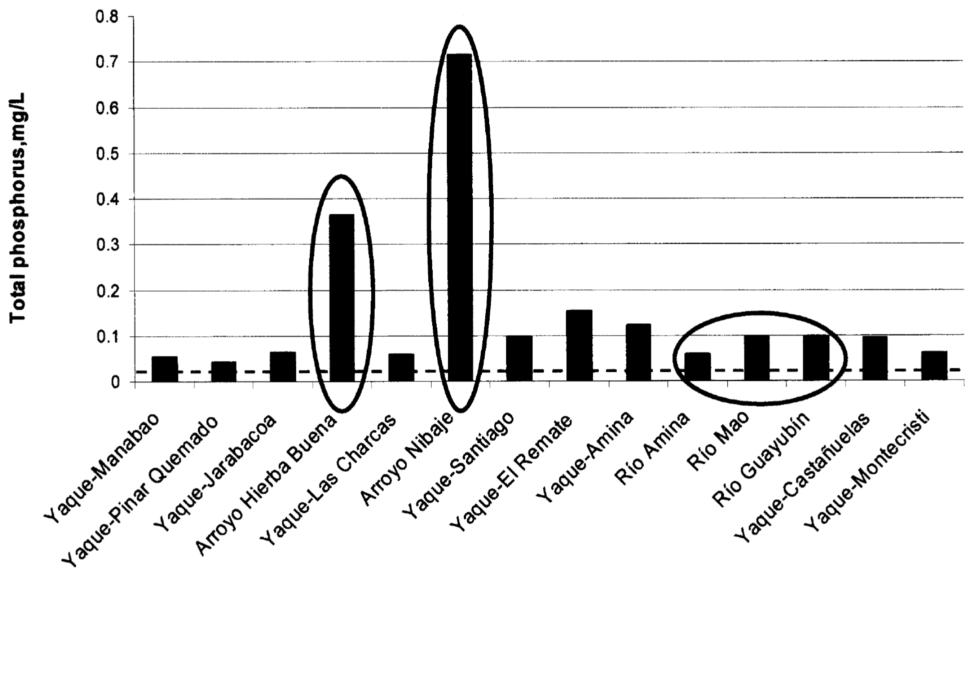


Figure 16 Mean total phosphorus from June to August 2004

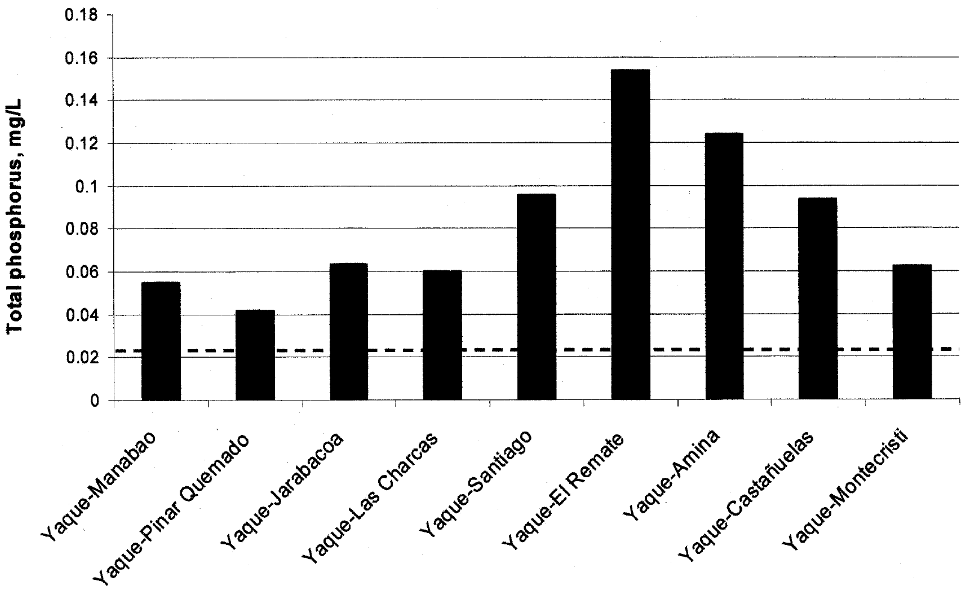


Figure 17 Mean phosphate from June to August 2004. Circled bars are tributaries

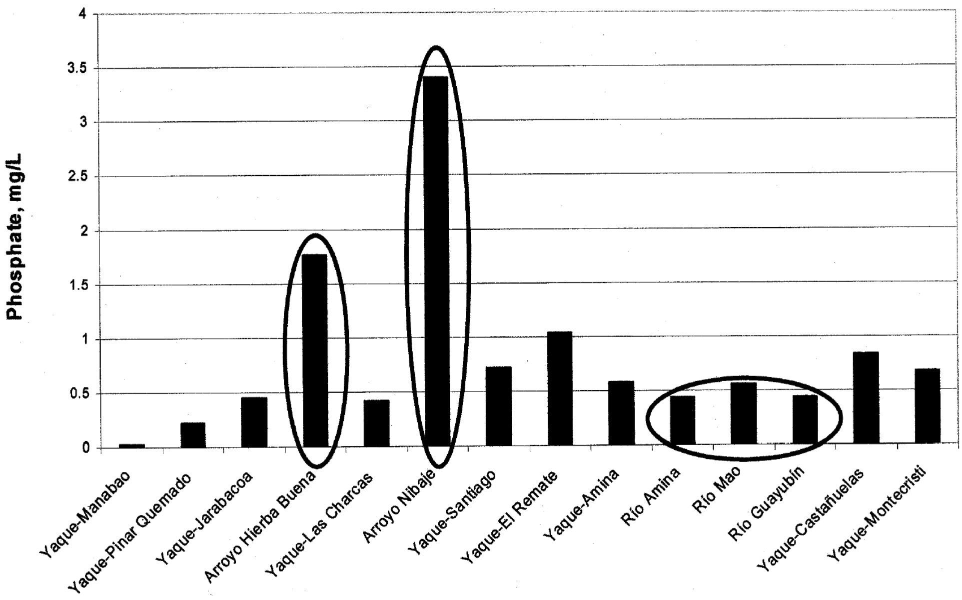
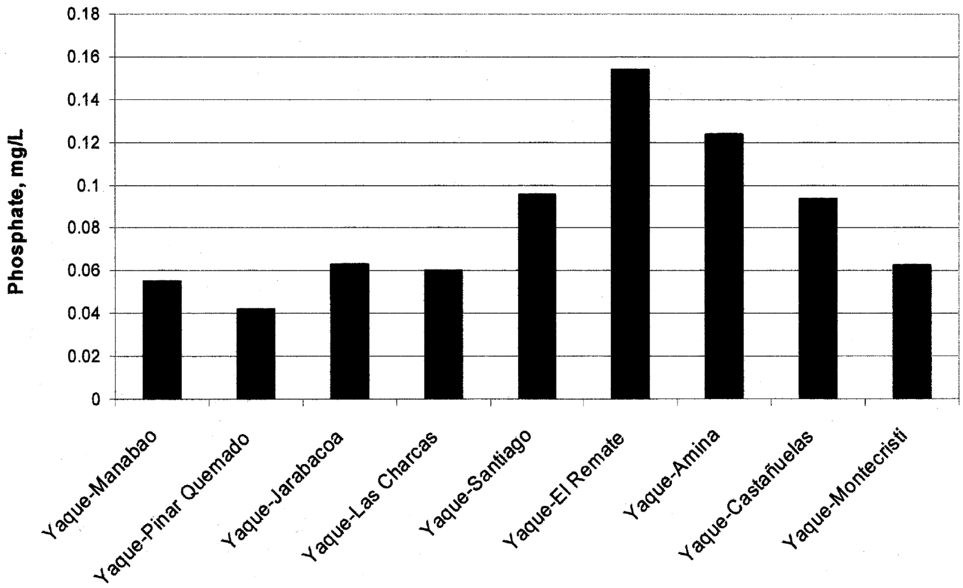


Figure 18 Mean phosphate from June to August 2004



5 Discussion

The literature indicates that water quality upstream from Santiago is significantly superior to that in downstream areas as high volumes of organic matter input notably diminish DO at and below Santiago. Reference is also made to chemical oxygen demand being very high and likely due to agrochemicals and industrial pollutants (Abt Associates, Inc., 2002). The same group reported that of the ten wastewater treatment plants on the river, nine are in Santiago and one in Montecristi, the latter frequently non-functional. However, the authors noted that DO was consistently above 5 mg/l in the river. An earlier two-month study by INRHI and GTZ (1993) also found DO above 5 mg/l in the river.

A similar situation is common in tropical and subtropical regions lacking centralised or operational wastewater treatment facilities. Mean dissolved oxygen was depressed to as low as 1.8 mg/l in the most polluted urban stream tributaries of the Piracicaba River, Brazil (Daniel et al., 2002). Dissolved oxygen decreases were entirely attributed to point sources of untreated urban sewage. Similarly DO concentrations in another tropical urban stream study in Accra, Ghana showed mean values ranging from 1.48 mg/l to 4.88 mg/l (Thorne et al., 2000).

Abt Associates, Inc. (2002) and Hartshorn et al. (1981) reported cation and anion concentrations increasing up to 30-fold after passing through Santiago and with the addition of agricultural drainage to the mix. They also indicated that water volume contributed to the river from major tributaries, Amina and Mao Rivers, likely diluted electrical conductivity in Yaque del Norte.

In other tropical and substropical studies, conductivity was reported to range in least polluted waters between 0.05 mS/cm and 0.1 mS/cm. Conductivity was approximately three times higher in most polluted streams in the Piracicaba River basin, Brazil (Daniel et al., 2002) than in the river itself, between 0.4 mS/cm and 0.6 mS/cm. These increases were entirely attributed to point sources of untreated urban sewage. Similarly high conductivity in another tropical urban stream study in Accra, Ghana showed conductivity ranging from 0.232 mS/cm to 1.252 mS/cm from the least impacted to the most impacted sites (Thorne et al., 2000). In Tanzania, waters coursing through an agricultural watershed were reported to have conductivity as high as 48 mS/cm (Ngoye and Machiwa, 2004). In a study of a heavily-irrigated region of Australia, Jackson et al. (2001) noted that the Murray-Darling basin, supplying approximately one-half of Australia's agricultural output, has capped water extraction in response to salinisation from irrigation in order to balance the demand between rising human population and agriculture. These caps reverted water diversions to 1993–1994 levels.

Turbidity, generally measured in nephelometric turbidity units (NTU), is one indicator of sediment load in precipitation runoff. Sediment particles, mainly of silt and clay or mud, may either become suspended in the water due to wind and currents, or they may be washed into the water by runoff. This will vary according to precipitation and land use. Some turbidity will be due to organic matter, such as that from algae/phytoplankton cells and other microorganisms. Turbidity due to inorganic matter such as mud can clog fish gills, bury and smother eggs or other small benthic life stages of aquatic organisms, transport sorbed contaminants and induce light attenuation (which will affect photosynthesis) (Davies-Colley and Smith, 2001).

Nutrient input has its origin in natural, or background, sources, as well as cultural sources. In the USA, natural background total nitrogen (TN) varies from 0.02 in the drier western USA to 0.5 mg/l in the southeastern US coastal plain. Background total phosphorus (TP) varies from less than 0.006 in the drier west to more than 0.08 mg/l in the Great Plains (Smith et al., 2003). Nitrogen and phosphorus are major contributors to aquatic over-fertilisation, or eutrophication. As evidenced specifically by high TP, surface waters in the entire Yaque del Norte River basin are eutrophic. Abt Associates, Inc. (2002) reported that ammonia only exceeded 0.5 mg/l, the water quality norm for DR (SEMARN, 2003) at Navarrete near the Yaque-El Remate site in the current study.

High levels of phosphorus are generally reported for surface waters from Puerto Rico (Sotomayor-Ramírez et al., 2001). The authors indicate that the threshold limit for eutrophication is considered to be 0.1 mg/l, but concentrations as low as 0.02 mg/l may pose a problem. TP in the middle 50% of samples ranged from 0.04 mg/l to 0.29 mg/l, with a mean of 0.3 mg/l. Phosphorus loading was attributed to a variety of organic sources, including agricultural non-point, background non-point and point sources. There were no seasonal differences in TP concentrations as expected after hypothesising that phosphorus would be higher in higher rainfall months due to runoff. Others have found similar results. In Georgia, USA, Nearing et al. (1993) found no relationship between flow rates and phosphorus concentrations in water coursing through forest and pasture land. Kwong et al. (2002) indicated that nitrogen and phosphorus movement is linked to sediment in runoff and does not behave differently between temperate and tropical regions. In DR, Jobin (1999) reported that a reservoir construction project on the Nizao River in southern DR, Lake Valdesia had 0.01 mg/l TP in 1979 and by 1990–1991, TP was 0.05 mg/l with increasing incidence of algal blooms.

Water use in rural tropical regions ranges from settings such as the relatively pristine and sparsely inhabited Peruvian Amazon where most people obtain their drinking water and dispose of their untreated wastes into the same source without harm (McClain et al., 2001) to the situation in most tropical regions where rivers are heavily impacted by human activities, as mentioned earlier here (Daniel et al., 2002; Ngoye and Machiwa, 2004; Thorne et al., 2000). In all cases, wastewater treatment and the preservation of natural water purification features such as riparian buffers and wetlands are recommended.

Development projects in tropical areas often disproportionately focus on land use and largely ignore aquatic resources. Maintenance of good water quality is essential to support aquatic resources such as fisheries (Brinson, 1987). On a global basis, with climate change forecasts, many world regions may become even more limited in terms of freshwater availability. Freshwater run-off may increase 10% in future decades due to climate change while human population is projected to increase 30%. As an example of current aquatic conditions, Jackson et al. (2001) report that up to 20% of all freshwater species worldwide are threatened or extinct due to habitat degradation. In a recent assessment of macroinvertebrate fauna at 26 sites in the Yaque del Norte watershed, Soldner et al. (2004) found that deteriorating water quality was associated with declining richness and diversity indicators, in spite of not being able to remove the effect of high vs. low altitude macroinvertebrate composition. For DR in general, Russell (1991) reported that with an approximate 10% remaining forest cover in a national territory that is 60% mountainous, many formerly high-volume rivers are drying up due to deforestation. Therefore, the major cause of decreased river volume in DR is deforestation, and in concert with deforestation and mountainous terrain, soil erosion is the number one natural resource problem. Soils washed into rivers may irreversibly alter aquatic fauna habitat by degrading water quality and smothering habitat and fauna with sediment (Davies-Colley and Smith, 2001). For example, the Tavera hydroelectric reservoir, on the Yaque del Norte River, had accumulated 20 metres of sediment behind the dam in less than 20 years after its construction (Russell, 1991). In terms of the coastal environment, the literature indicates that nutrients, suspended sediments and other pollutants discharged by rivers into coastal areas impact the coastal zone, especially coral reefs (Devlin et al., 2001).

In addition to soil loss and sedimentation, nutrient input from a river's watershed has a major impact on water quality. In comparing temperate vs. tropical watersheds, non-point sources of pollutants are the major source in the USA (Carpenter et al., 1999), whereas point sources are more significant in tropical developing countries (Ometo et al., 2000). Over-fertilised waters due to nutrients such as nitrogen and phosphorus lead to eutrophication. Eutrophic waters commonly contain large blooms of algae and are a major concern in surface waters because they indicate degraded water for aquatic fauna. Most of the problem originates from surplus phosphorus, the main culprit in eutrophication, and nitrogen (Carpenter et al., 1998).

Withers and Lord (2002) comment on the issue of land management and control of excess nutrients in surface waters in the UK. In the Nuese River, North Carolina, USA, nutrients from 441 point dischargers and 554 concentrated animal operations have created a situation whereby the river basin is a nutrient sink; that is, nutrients are imported from outside the watershed. Under conditions of intensive precipitation, nutrients can create severely degraded water conditions in the river and downstream in the estuaries (Glasgow and Burkholder, 2000). On the other hand, over a 20-year period of careful management, nitrogen and phosphorus levels were significantly diminished in four Ohio, USA, rivers after introduction of better fertiliser and manure management (Richards and Baker, 2002). If the major loading is non-point, again, the preservation and/or creation of riparian vegetation, wetlands and floodplains may play a role in mitigating this pollution load.

6 Conclusion

The current research represents an effort to contribute to the assessment and knowledge database of water quality of the Yaque del Norte River watershed for managers and regulators of this resource. The river is the longest in DR and also encompasses the country's largest watershed. Its origin is a pristine high-mountain national park. Downstream it is the source of drinking for a significant portion of the country's population and provides irrigation water for much of the country's agricultural land. In its course from mountains to sea, it receives treated and untreated wastewater from several municipalities, including the second-largest population centre in the country (Santiago) and receives non-point source contaminant input from agricultural lands and deforested mountain slopes.

With an expanding human population, intensive agriculture employing synthetic fertilisers and pesticides and against the backdrop of generally mountainous terrain, much of which requires irrigation to support agriculture, the challenge of satisfactorily managing the Yaque del Norte River land and water resources for all stakeholders is critical and urgently needs to be addressed.

Acknowledgements

The senior author is grateful for the support of the Fulbright Scholar Program, host institution Pontificia Universidad Católica Madre y Maestra (PUCMM) and the Winthrop University Research Council for financial and infrastructure support for conducting this research. Atahualpa López, of Centro de Estudios Urbanos y Rurales, PUCMM, prepared the watershed maps.

References

Abt Associates, Inc. (2002) *Diagnóstico Ambiental y Análisis Económico/Fiscal*, Informe Final. República Dominicana, Secretaría de Estado de Medio Ambiente y Recursos Naturales, Proyecto de Políticas Nacionales de Medio Ambiente, Préstamo LIL 4293-DO, Capítulo 4, Calidad de Agua, Vol. 3.

Banco Mundial (2004) *República Dominicana: Prioridades Ambientales y Opciones Estratégicas, Análisis Ambiental del País*, Unidad Administrativa de Países Caribeños Desarrollo Ambiental y Socialmente Sostenible Región de América Latina y el Caribe.

Bolay, E. (1997) *The Dominican Republic, a Country between Rain Forest and Desert: Contributions to the Ecology of a Caribbean Island*, Margraf Verlag, Weikersheim, Germany.

Brinson, M. (1987) 'Controlling development to conserve aquatic resources: freshwater fisheries including aquaculture, Module 13', in Lugo, A.E., Clark, J.R. and Child, R.D. (Eds.): *Ecological Development in the Humid Tropics, Guidelines for Planners*, Winrock International Institute for Agricultural Development, Morrilton, AR, pp.339–360.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and Smith, V.H. (1998) 'Nonpoint pollution of surface waters with phosphorus and nitrogen', *Ecological Applications*, Vol. 8, No. 3, pp.559–568.

Carpenter, S.R., Ludwig, D. and Brock, W.A. (1999) 'Management of eutrophication for lakes subject to potentially irreversible change', *Ecological Applications*, Vol. 9, No. 3, pp.751–771.

Consejo para el Desarrollo Estratégico de la Ciudad y el Municipio de Santiago, Inc. (2002) *Santiago 2010: Plan Estratégico de Santiago*, Santiago, República Dominicana.

Daniel, M.H.B., Montebello, A.A., Bernardes, M.C., Ometto, J.P.H.B., DeCamargo, P.B., Krusche, A.V., Ballester, M.V., Victoria, R.L. and Martinelli, L.A. (2002) 'Effects of urban sewage on dissolved oxygen, dissolved inorganic and organic carbon, and electrical conductivity of small streams along a gradient of urbanization in the Piracicaba River basin', *Water, Air, and Soil Pollution*, Vol. 136, pp.189–206.

Davies-Colley, R.J. and Smith, D.G. (2001) 'Turbidity, suspended sediment, and water clarity: A review', *Journal of the American Water Resources Association*, Vol. 37, pp.1085–1101.

Devlin, M., Waterhouse, J. and Brodie, J. (2001) 'Community and connectivity: summary of a community based monitoring program set up to assess the movement of nutrients and sediments into the Great Barrier Reef during high flow events', *Water Science and Technology*, Vol. 43, pp.121–131.

Glasgow, H.B. and Burkholder, J.M. (2000) 'Water quality trends and management implications from a five-year study of a eutrophic estuary', *Ecological Applications*, Vol. 10, pp.1024–1046.

Hartshorn, G., Antonini, G., DuBois, R., Harcharick, D., Heckadon, S., Newton, H., Quesada, C., Shores, J. and Stables, G. (1981) *La República Dominicana: Perfil Ambiental del País, Un Estudio de Campo*, AID Contract No. AID/SOD/PDC-C-0247, JRB Associates, Virginia, USA.

INDRHI, República Dominicana and GTZ (Gesellschaft für Technische Zusammenarbeit), República Federal de Alemania (1993) *Relevamiento de Calidad de Agua en el Río Yaque del Norte, República Dominicana*, Proyecto 'Fortalecimiento del INDRHI en actividades hidrológicas', Informe No. 74.

Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight, D.M., Naiman, R.J., Postel, S.L. and Running, S.W. (2001) 'Water in a changing world', *Ecological Applications*, Vol. 11, pp.1027–1045.

Jobin, W. (1999) *Dams and Disease: Ecological Design and Health Impacts of Large Dams, Canals and Irrigation Systems*, E. & F.N. Spon, Taylor & Francis Group, London, UK.

Kwong, K.F.N.D., Bholah, A., Volcy, L. and Pynee, K. (2002) 'Nitrogen and phosphorus transport by surface runoff from a silty clay loam soil under sugarcane in the humid tropical environment of Mauritius', *Agriculture Ecosystems and Environment*, Vol. 91, Nos. 1–3, pp.147–157.

McClain, M.E., Aparicio, L.M. and Llerena, C.A. (2001) 'Water use and protection in rural communities of the Peruvian Amazon basin', *Water International*, Vol. 26, No. 3, pp.400–410.

Nearing, M.A., Risse, R.M. and Rogers, L.F. (1993) 'Estimating daily nutrient fluxes to a large Piedmont reservoir from limited tributary data', *Journal of Environmental Quality*, Vol. 22, pp.666–671.

Ngoye, E. and Machiwa, J.F. (2004) 'The influence of land-use patterns in the Ruvu river watershed on water quality in the river system', *Physics and Chemistry of the Earth*, Vol. 29, pp.1161–1166.

Núñez Molina, L.N. (1987) *El Territorio Dominicano*, Editora Corripio, C. por A., Santo Domingo, República Dominicana.

Ometo, J.P.H.B., Martinelli, L.A., Ballester, M.V., Gessner, A., Krusche, A.V., Victoria, R.L. and Williams, M. (2000) 'Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba River basin, south-east Brazil', *Freshwater Biology*, Vol. 44, pp.327–337.

Richards, R.P. and Baker, D.B. (2002) 'Trends in water quality in LEASEQ rivers and stream (northwestern Ohio), 1975–1995', *Journal of Environmental Quality*, Vol. 31, pp.90–96.

Rodríguez Taveras, R.I. (2000) *El Río Yaque del Norte Desde el Pico Duarte Hasta Montecristi*, Self-Published, Dominican Republic.

Russell, F.A. (1991) 'Land use: erosion and poverty in the Dominican Republic', *The Centennial Review*, College of Arts and Letters, Michigan State University, Vol. XXXV, No. 2, pp.323–334.

SEMARN (Secretaría de Estado de Medio Ambiente y Recursos Naturales, República Dominicana) (2003) *Norma Ambiental Sobre Calidad del Agua y Control de Descargas*, Santo Domingo, República Dominicana.

Smith, R.A., Alexander, R.B. and Schwarz, G.E. (2003) 'Natural background concentrations of nutrients in streams and rivers of the conterminous United States', *Environmental Science and Technology*, Vol. 37, No. 14, pp.3039–3047.

Soldner, M., Stephen, I., Ramos, L., Angus, R., Wells, N.C., Grosso, A. and Crane, M. (2004) 'Relationship between macroinvertebrate fauna and environmental variables in small streams of the Dominican Republic', *Water Research*, Vol. 38, pp.863–874.

Sotomayor-Ramirez, D., Martinez, G. and Olivieri, L.J. (2001) 'Phosphorus status of stream waters in Puerto Rico: 1989–1997', *Journal of Agriculture of the University of Puerto Rico*, Vol. 85, pp.1–15.

Thorne, R.S.J., Williams, W.P. and Gordon, C. (2000) 'The macroinvertebrates of a polluted stream in Ghana', *Journal of Freshwater Ecology*, Vol. 15, No. 2, pp.209–217.

Withers, P.J.A. and Lord, E.I. (2002) 'Agricultural nutrient inputs to rivers and groundwaters in the UK: policy, environmental management and research needs', *Science of the Total Environment*, Vol. 282, pp.9–24.