MANAGING FRESHWATER INFLOWS TO ESTUARIES

Impacts of Altered Freshwater Flows to Estuaries: Yuna Watershed and Samana Bay Estuary. Draft Profile.

Jim Tobey

Tobey, J. (2004). Impacts of altered freshwater flows to estuaries: Yuna river watershed and Samana Bay, Dominican Republic: Draft Profile. Includes: Ortiz, A. Appendix 1: Water Budget of the Yuna River Watershed. Narragansett, RI: Coastal Resources Center, University of Rhode Island and The Nature Conservancy.

Impacts of Altered Freshwater

Flows to Estuaries

Yuna River Watershed and Samana Bay

Dominican Republic

Draft Profile

September 1, 2004

Prepared by the Coastal Resources Center and the Nature Conservancy

With the support of the

Water Team, USAID/Washington

Table of Contents

Figures (separate files)

Acronyms

CANARI	Instituto Caribeño de Recursos Naturales Caribbean Natural Resources Institute
CAD	Consorcio Ambiental Dominicano Dominican Environmental Consortium
CDE	Corporación Dominicana de Electricidad Dominican Electric Corporation
CEBSE	Centro para la Conservación y Ecodesarollo de la Bahía de Samaná y su Entorno Center for the Conservation and Eco-Development of Samana Bay and its Surroundings
CMC	Center for Marine Conservation, United States
HELVETAS	Swiss Association for International Cooperation
INDRHI	Instituto Nacional de Recursos Hidráulicos National Institute of Hydrological Resources
INAPA	Instituto Nacional de Aqua Potable y Abastecimiento National Institute for Potable Water and Sewage Systems
ONAPLAN	Oficina Nacional de Planificación National Planning Office
Pronatura	Fondo Pro Naturaleza Fund for Nature
SEMARN	Secretaría de Estadao del Medio Ambiente y Recursos Naturales Secretary of the Environment and Natural Resources

Preface

This profile is being developed as the first product of a pilot project sponsored by USAID and executed by a partnership of the Coastal Resources Center of the University of Rhode Island and The Nature Conservancy in the Dominican Republic and the United States. The goal of the project is to develop and apply methods for assessing the impacts of changes in fresh water inflows on estuaries and to work with governmental and non-governmental stakeholders to formulate action strategies to address the consequences of such changes. The project began at the end of 2003 and will continue through 2005. The methods and lessons learned from the pilot project are intended to provide guidance to similar analyses and planning of other watersheds and estuaries around the world.

This profile will be continually updated throughout the course of this project. The process to develop the profile thus far has involved a desk review of existing literature, a reconnaissance trip to meet with local experts, stakeholders, and key institutions, and three types of rapid science analyses. The comprehensive review and synthesis of existing literature and the preparation of this profile, including the integration of information from meetings and scientific analyses was led by James Tobey of the Coastal Resources Center. The reconnaissance trip in April was coordinated by Jeannette Mateo and the TNC office in Santo Domingo. James Tobey, Chuck DeCurtis (Director of Aquatic Conservation, TNC, Harrisburg, PA), and Antonio Ortiz (National Institute of Hydrological Resources, Santo Domingo), participated in the reconnaissance trip in April 2004 that included meetings in Santo Domingo and visits to key points along the Yuna River system and Samana Bay.

The first science analysis involved a brief characterization of the natural patterns of river flows into Samana Bay and assessment of whether or not those patterns have been substantially altered during the past four decades. This was conducted by Andy Warner (Senior Advisor for Water Management, TNC, University Park, PA). The second was an analysis of the water budget for the estuary, quantifying all inflows and outflows of water on an average annual basis. This was supervised by the TNC office in Santo Domingo and conducted by Antonio Ortiz and Jesús Medina. This work involved field data collection. The third science analysis involved the preparation of conceptual models of the ecology of Samana Bay and digital maps of land cover and land use in the watershed and Samana Bay region. This was lead by Chuck DeCurtis, Director of Aquatic Conservation, TNC, Harrisburg, PA.

We wish to extend our appreciation to all those on the extended project team who offered their invaluable insights and guidance to this work, especially Stephen Olsen, Director of the Coastal Resources Center; Pam Rubinoff, Program Manager, the Coastal Resources Center; Lynne Hale, Director of Marine Initiatives, TNC; Francisco Nuñez, Freshwater Team Leader, TNC, Santo Domingo; Brian Richter, Director of Sustainable Waters Program, TNC; and, Richard Volk, USAID, Washington. We also thank all the individuals in the Dominican Republic that we have met with for their time and insights and to the TNC Ecoregion Program for their cooperation and help in locating maps.

Profile of the Yuna River Watershed and Samana Bay

Dominican Republic

1. Introduction

This report provides an overview of the Yuna watershed and Samana Bay with a focus on the quantity and quality of freshwater flows and their relationship with the ecology and human uses of the estuary of Samana Bay. It is prepared as part of an innovative project initiated by USAID to develop and apply methods for assessing the impacts of changes in water volumes, pulsing and quality on estuaries and to work with governmental and non-governmental stakeholders to formulate action strategies to address the consequences of such changes. Pilot initiatives have been launched in both the Dominican Republic (the Yuna watershed/Samana Bay) and Mexico (Grijalva- Usumacinta- Candelaria watersheds/Laguna de los Terminos).

The primary goal of the Freshwater to Estuaries Project is to test and refine science based methods that contribute to participatory governance of water resources in coastal areas and to forecast potential social and ecological outcomes associated with different water management options.

This profile is based on a comprehensive review of existing literature, maps and data, meetings with local experts, and rapid assessments of the Yuna watershed and Samana Bay ecology, water budget, and Yuna River flow patterns. The profile will be reviewed and discussed at a Working Group meeting that will be convened in Santo Domingo. The goal of this meeting is to invite comments and guidance on priorities for additional data collection and analysis in the next phase of this pilot initiative, identify information gaps with respect to governance, socioeconomics and stakeholder issues, and identify plausible scenarios of changes to freshwater inflows to Samana Bay.

2. Overview of the Watershed

The Dominican Republic can be divided into 14 hydrological basins. The Yuna River basin is in the north-central part of the country. This basin drains the southern slopes of the Cordillera Septentrional and a small part of the Cordillera Central. The major river in this basin is the Yuna River, which carries moderate quantities (>10 to 100 m^3/s) of fresh water year round. SEMARN (2001) reports that the Yuna is 208 km in length and the largest river in the country in terms of flow of fresh water. Our estimates from gauging station data show the inflow from the Yuna watershed to be an annual average of 102.4 m^3/s (see Appendix 1). Taking into account the returned water from rice irrigation, the estimated net inflow is 105.5 m^3/s.[1] Average annual precipitation in the watershed is between 1,170 and 2,250 mm (Office of the President, 2002). Due to the large quantity of precipitation in this basin, as well as the poor drainage, a large area in the lower Yuna periodically floods.[2]

2.1 Boundaries of the Yuna Watershed and Tributaries

In terms of the drainage basin, the watershed of the Yuna River is the second largest, providing 20 percent of the runoff for the country (the Yaque del Norte River provides 25 percent of the runoff for the country). The Yuna watershed has a perimeter of 420 kilometers and an area of 5,498 km^2 (SEMARN, 2001). The boundaries of the Yuna watershed are shown in Figure 1.

The source of the Yuna River is located in the east part of Cerro Montoso and south of Firme Colorado. From its source, the river flows to the southwest and later it turns to the west. After converging with the Blanco River, in the community of El Torito, the river turns to the northwest. After converging with Blanco River, the Yuna turns to the northeast crossing to the north of the city of Bonao. The Blanco River tributary contains very small (>0.1 to 1 m^3/s) to

[1] SEMARN reports the annual inflow from the Yuna to be 91.8 m^3/s.
[2] In November 2003, heavy rains resulted in an overflow of the banks of the Yuna river, as well as its tributaries, flooding an area of 65 km (INDRHI, 2003b). The floods affected housing and 47,270 people

small quantities of fresh water. The source of the Blanco River is Valle Nuevo National Park. In the north part of Alto Bandera hills, Blanco River has Tireo River as a tributary. In the Tireo sub-watershed there is almost a total lack of vegetation cover due to intense agricultural activities and erosion. It is the sub-watershed with the largest sediment production.

The Yuna converges with the Masipedro River in Bonao and shifts to the east to where it is joined by the Maimón and Yuboa Rivers. The source of the Masipedro River is the protected area of Las Neblinas. The Maimón and Yuboa Rivers begin in the north part of Loma de los Chicarrones and Cuesta La Vaca, respectively. In these sub-watersheds a large part of the countryside is used for livestock production but there are also some wood production ranches. After Maimón, the Yuna shifts it direction again towards the north, sometimes changing direction to the northeast and maintaining that course until converging with Camú River where the Yuna continues its direction to the east until crossing the plain of the lower Yuna.

The Camú and Jima Rivers are the major tributaries to the Yuna and carry small to moderate (>1 to 10 m^3/s) quantities of fresh water year round (US Army Corps of Engineers, 2002). The Camú River begins in Loma de Casabito, within the borders of the Ebano Verde Scientific Reserve. The Camú River itself has several tributaries: Licey, Cenovi, Jaya, Guiza, and Cuaba (INDRHI, 2003a). The upper reaches of the Camú and Jima Rivers are swift streams with steep gradients. However, the rivers begin to slow and become meandering, like the Yuna River, once out of the mountains. The upper and medium-high parts of the Camú and Jima Rivers, as well as the sub-watershed of Maimón, Arroyo Blanco, and Masipedro have good vegetation cover. In this area, plantations of pine, ebony, long leaf trees, coffee and cacao can be observed. Rice farming dominates the lower part of the Camú (see Figure 2).

The Yuna splits seven kilometers from Samana Bay in the community of Agua Santa de Yuna. This division took place at the end of the 1950’s when a ditch was built to channel water

---

were evacuated (Red Cross, 2003). Total damage to national irrigation systems, agriculture, aqueducts, and potable water was estimated at RD$187 million (INDRHI, 2003b).

from the river to irrigate fields located in the Barracote area. Due to the instability of the soil on the sides of the channel, rain and flooding increased the size of the ditch to such an extent that the Yuna was joined with the Barracote River. The inflows to Samana Bay by this drainage are now greater than the inflows by its natural drainage in the proximity of Sanchez. Measurements conducted August 17th, 2004 showed a flow of 22.2 m^3/s in the old drainage of the Yuna and 144.8 m^3/s in the Barracote drainage. These measurements were taken at a time of heavy rainfall. The Yuna, through the Barracote River receives inflows from springs and various streams and lagoons from the hills of Los Haitises, including Laguna Cristal, Laguna la Cuevas and the streams Paraguay and Barraquitos.

The Yuna watershed contains several national parks (Valle Nuevo, Los Haitises, and Montaña La Humeadora), protected areas (Las Neblinas), Scientific Reserves (Ebano Verde) and a biological reserve (Idelisa Bonnelly de Calventi in Samana Bay). They are serving an important function because they have been largely reforested, thereby reducing erosion and surface water runoff as well as the spread of biological and chemical contamination from household and agricultural wastes (US Army Corps of Engineers, 2002).

In summary, the most important tributaries of the watershed are the following:

- Arroyo Blanco, where construction of a dam for generation of electricity is being considered
- Tireito, where Tireito and Arroyón dams are located
- Blanco River, where Blanco dam is located.
- Avispa stream, where the Bonao aqueduct is located and further downstream is the Yuna Caracol canal
- Masipedro River, where Los Arroces canal is located
- Yuboa River, where Yuboa (Aniana Vargas) dam and the Yuboa canal are located
- Maimón River, where at the lowermost part of the downstream confluence the Hatillo dam is located, which is the most important dam in terms of water storage capacity and flood control. Downstream of the dam is Yuna Los Corozos canal

- Maguaca River and Chacuey River, where feasibility studies for multiple purpose dams have been initiated
- Camú River, where Rincón dam is located as well as the Camú-Jamo canal and the system of canals of the Jima (East Margin and West Margin)
- Payabo River, where Payabo canal is located, and where downstream of its confluence with the Yuna are the dikes for the rice farm irrigation projects Aglipo I (that direct waters to the neighboring watershed of the Nagua River) and Aglipo II (that direct waters to the Aguacate Guayabo region)
- Other tributaries to the Yuna through the Barracote are the streams Barraquito, Paraguay, and Cristal, and the lagoons Cristal and Las Cuevas

2.2. Gauging Stations and River Flow Patterns

In the Yuna watershed and its tributaries there are 20 hydrometric stations operated by INDRHI. All the stations had automatic measurement equipment until the floods of Hurricane George swept them away in September 1998. To date, this equipment has not been replaced. Six key stations for the purposes of this study are the following (see Figure 1):

- Los Quemados station is located five kilometers to the west of Bonao. At Los Quemados the annual mean flow was 15.8 m^3/s. for the period between 1962 and 1979. The maximum flow observed at the station was 56.5 m^3/s in September 1976 and the minimum was 2.4 m^3/s in April 1965.
- Maimón station is located 1.5 km from the town of Maimón. At this station the annual mean flow was 5.2 m^3/s, for the period between year 1968 and 2000. The maximum flow observed in the station was 40.0 m^3/s in September 1988 while the minimum was 0.12 m^3/s in September 1991.
- La Bija station is located 4 km from the town of Pimentel town along the road from Las Matas de Cotuí to Pimentel. At La Bija station, the annual average water flow was 36.2 m^3/s. for the period between 1968 and 2002. The maximum flow observed in this station was 145.9 m^3/s in November 1996 and the minimum was 2.8 m^3/s during July 1975.
- Villa Riva is located in Villa Riva downstream of the road and bridge that goes to La Ceiba de los Pájaros. At this station the average annual flow was 89.4 m^3/s for the period between 1956-1992. The maximum flow observed at the station was 402.5 m^3/s during

May 1979 and the minimum was 6.1 m^3/s during March 1977. Average maximum monthly flow for this station is 162 m^3/s in May, 114 m^3/s in November, 57 m^3/s in January and 42 m^3/s in July (Office of the President, 2002).

- Payabo station is located in the Haitises area, near the town of Rincon Claro, 4km from the confluence with the Ara River. At this station the average annual flow was 5.8 m^3/s for the period between 1971-1995. The maximum flow observed at the station was 22.7 m^3/s during May 1983 and the minimum was 0.47 m^3/s in March 1977.
- El Limón station is the most downstream control point of the Yuna River prior to the split at Agua Santa de Yuna. El Limón is approximately 40 km upstream from Samana Bay; it is located 1.5 km downstream of the bridge at La Reforma. The average annual flow at this station was 102.4 m^3/s, for the period between 1968-2003. The maximum flow observed at the station was 374.7 m^3/s in May 1981 and the minimum was 10.9 m^3/s during April 1975.

The general pattern of seasonal flows on the Yuna River has been noted to include a dry season that runs from December through March and a wetter period from April through November, with May-June and October-November as the most likely months for larger flows and flooding. The data from the gauging stations at El Limon and Villa Riva mostly confirm this seasonal pattern (see Appendix 2). There is an extended period when the Yuna River provides Samana Bay stable and low freshwater inputs, as well as two very distinct times of the year when the Yuna rises and provides large freshwater inflows to the Bay.

However, analysis of the data (Appendix 2) suggest that average flows during December are every bit as large as those experienced in October and November, and that the variability of December flows from year to year is high and very characteristic of other wet season months. Moreover, while July through September have been described as part of the wet season, flow variability from year to year during this period is low and more characteristic of dry season months. In conclusion, there appear to be two dry seasons and two wet seasons.

- Dry season 1 (January-March)
- Wet Season 2 (April-June)

- Dry Season 2 (July-September)
- Wet Season 2 (October-December)

When modeling ecological responses in the estuary to freshwater inflows it is important to distinguish the effects of low flows from high (peak) flows and the seasonality of the low or high flows (see Figure 3). Low flows usually play very different ecological roles than high flows do. In addition, dams tend to have very different impacts on low flow characteristics versus high flow characteristics. By distinguishing two different dry seasons and two different wet seasons, we need to be concerned about eight different flow conditions (low flows in four seasons, high flows in four seasons).

The Camú River—the Yuna's largest tributary—exhibits the same "bimodal" seasonal pattern of wet periods as the Yuna, although flows during the dry January to March period are consistently higher than those experienced between July and September. Similar seasonal flow patterns are also seen further up on the Yuna (Los Quemados gauging station) and on the small tributary of the Maimón (see Appendix 2, Figure 4).

3. Overview of the Estuary of Samana Bay

3.1 Physical and Ecological Features

Samana Bay is the largest semi-enclosed bay in the Caribbean (Lopez Ornat, 1996) and most important estuary in the country. The bay has a rectangular form with a length of about fifty kilometers and width between 9 and 17 km. The current is from the south and trade wind from the northeast creating an abayment with the implication of a potentially long residence time of contaminants in the water column. The bay and the waters around Samana peninsula contain small islands, shoals and patches of coral formations, and extensive seagrass beds (see Figure 4). Seagrass beds are located on the north shore of the bay around the town of Samana and on the south shore along the coast of Los Haiteses and San Lorenzo bay (near Sabana de la Mar). "Thalassia" or sea turtle grass is the most abundant on the south shore, covering 40 percent of the bottom area (CEBSE, 1993a). Seagrass beds are favored habitat for various commercial conch species, but are also easily damaged by increased turbidity or other water quality degradation.

With respect to coral reefs, the greatest area of reef development is located in the eastern end of the Bay. Freshwater and turbidity from land-based sediments from the Yuna and Barracote Rivers prevents reefs from forming further in the Bay.

The area receives the highest rainfall in the country (average 2,500 mm/year), as trade winds blowing from the east or northeast first drop their moisture upon hitting the Samana Bay area (TRD, 1991). The town of Samana has 200 rain days per year (Pronatura, 1993). The predominant vegetation of the area is degraded, subtropical, humid forest (TRD, 1991).

The bay is the most important sanctuary for humpback whales in the North Atlantic. Every year, from January to March, it is visited by a population of some 1,000 humpback whales that depend on the bay for breeding and nursery habitat. The area used by the whales is at the mouth of the bay, but there are people who can recall seeing whales all the way up the west end of the bay. Besides boats, it is thought that increased turbidity and increasingly shallow waters prevent the whales from entering the bay further. Endangered species such as the green, hawksbill, and leatherback sea turtles as well as the West Indian manatee are also found in Samana Bay, although in increasingly limited numbers. Due to the nutrient-rich waters being supplied by the outflow of the Barracote and Yuna Rivers, the bay possesses potentially ideal nursery conditions to sustain large populations of commercially valuable shrimp, oysters, and fish. A study conducted for USAID in 1991 noted that the bay is considered one of the most important marine nurseries in the Caribbean (TRD, 1991).

The largest single mangrove stand in the country and Antilles region is located at the mouth of the Yuna River, encompassing the entire west end of Samana Bay from the town of Sánchez to the southern side of the mouth of the Barracote River (see Figure 4). With an area estimated by various studies at between 62 to 77.8 km^2, this mangrove forest makes up about 30 percent of total mangrove area in the country (SEMARN, 2001).[3] Samana Bay is therefore an area of special interest for the management and conservation of mangrove habitat. The mangrove forest is spread across the mouth of the Yuna and entire width of the western end of the Bay, extending more than five kilometers through the wetlands located in the proximities of Ciénega de Barracote, Laguna Cristal, Guayabo and Los Haitises. The most common species are red, white, black , and button mangrove (*rhizophora, laguncularia racemosa, avicennia germinans, and conocarpus erectus*). With the end of charcoal making in the 1990s, exploitation of mangrove forests is not currently a major concern. Also, Decree 531, December 27, 1990 prohibits the cutting of mangrove and recommends protection of mangrove ecosystems.

Mangrove and associated natural communities are integral to a healthy and viable estuarine food web. Mangroves are ecosystems of high biodiversity, highly productive in biomass, important for rearing of many juvenile and adult fish, crustacean and mollusk species. Typical production of mangrove leaf litter that serves as the base of the carbon and decomposer chain is approximately 3 tons/acre/year. The detritus resulting from the decomposition chain is flushed into the estuary and serves as a food source for many commercial species. Mangrove also protects coastal areas from erosion, removes sediments from rivers and improves the quality of estuarine water. Without the ecological functions provided by mangrove systems in Samana Bay, coral reef and sea grass beds will begin to degrade with associated loss of habitat utilized by many species. Key species in the Yuna-Samana Bay estuary that are dependent on mangrove communities are:

- Penaid shrimp – habitat and nursery
- Mangrove oyster – habitat

[3] We were told that the office of information (DIARENA) in the Ministry of Environment and Natural Resources has digitized maps of the mangroves of Samana Bay for the period 1968 to 2002. The data for 1968 and 1984 are from aerial photographs. The data for 1996 and 2002 are from Landsat satellite images. Researchers from Cornell University have mapped mangrove cover change in the lower Yuna River watershed using 1973 and 1985 Landsat images (Laba et al., 1997).

- Liza (a demersal estuarine species) – habitat and nursery
- Blue crab – habitat and nursery
- Grapsid crabs – habitat
- Yellowfin mojarra – habitat and nursery

Just to the south of the Yuna River delta is Los Haitises National Park. Los Haitises was designated as a forest reserve in 1968 to slow the erosion of forest resources, and it was declared a National Park in 1976. The Park encompasses 208 km^2 and is located near the center of an extremely permeable karstic substrate of marine origin encompassing an area of 1,600 km^2 (Stycos, 1994; TDR, 1991)[4]. There is virtually no surface water; rather erosion of the foundation has created a rugged topography with vertical drainage through caves and underground rivers. In total it is estimated that some 100 million m^3/ year of water circulate in the aquifer. The undulating karstic hills in the park may be unique in the world. The Park is rich in biodiversity. Studies have found that of the 239 bird species in the country 110 are found in the region and 13 are native only to the park zone. Seven-hundred and thirty four species of vascular plants have been inventoried in the Park of which 17 percent are endemic (CEBSE, 1993a).

In the wider area of Samana Bay, 35 species of reptiles (26 endemic to the country), 13 amphibian species, and 40 invertebrates have been reported (CEBSE, 1993a). The endangered West Indian manatee (*Trichechus manatus*) has been found along the coast of Los Haitises, San Lorenzo bay and the mouths of the Yuna and Barracote Rivers. This marine mammal is in danger of extinction as a result of exploitation for its meat.

TRD (1991) notes that it has been recommended to the National Parks Directorate that the Park's limits be extended to include the estuaries of the Yuna and Barracote Rivers and adjoining mangrove areas. In the early 90s, the area was proposed for designation as a Biosphere

[4] Karst topography is formed over soluble rock (limestone, dolomite) and is characterized by sinkholes, caves, and underground drainage.

Reserve (CEBSE, 1993a), but this was never acted on by the national Biosphere Reserve Committee.

The Sabana de la Mar-Nisibón coastal plain lies further to the west on the southern side of the Bay. This area is distinguished by its numerous fresh and brackish water lakes and wetlands and contains the Redonda and Limón Lagoon biological reserves.

Monitoring in the Bay during the period 1988-89 showed temperatures in the Bay between 25-32 degrees Celsius, pH between 7.7 and 8.5, and salinity in western part of the between 0-25 percent (CEBSE, 1993a). The waters in the western end of the Bay showed levels of total and dissolved organic material of 183 mg/L and 88 mg/L, and an average concentration of soluble phosphate of 6.19 mg/L.

Studies of zooplankton, also during 1988-89 show an abundance of organisms. The average density of zooplankton was 60,000 org/ m^3, with a maximum of 150,000 org/ m^3 (CEBSE, 1993a). The most productive areas are the mouths of the Barracote River and the coast of Los Haitises.

3.2 Freshwater Flow and the Ecology of the Samana Estuary

The ecology of mangrove and other estuarine communities of the Yuna-Samana Bay estuary are dependent on freshwater flows (see Figure 5). Alteration to the freshwater flows of the Yuna River and tributaries and associated salinity regime changes in the estuary has probably had extensive effects on the mangrove and estuarine community, such as loss of mangrove integrity, increasing sedimentation, and decreasing commercial fish catches. The mangrove swamp becomes more saline in the low flow period due to evaporation and saltwater intrusion. Evidence of change within the Bay include “shallowing” at the southern extent. During our field reconnaissance the fishermen who took us around the Bay attempted to get the boat in places that used to be open to shallow draft boats. This was all but impossible for us on this trip. Mud was churned up in areas that should from a geophysical pint of view, naturally be much deeper.

Reduced flows create an environment conducive to changing species dominance and zonation. Mangroves form distinct zones of species that reflect the salinity and topography of the surrounding environment. The duration and volume of freshwater flows and the salinity of tidal waters affect soil conditions and vertical stratification within the water column which determine the distribution of species within mangrove communities. Changes in the balance of fresh and marine waters may lead to increasing anoxic/anaerobic benthic conditions, decreased nutrient inputs, increasing sediment loads, increasing erosion, and upstream migration of the salt-wedge and the problems typically associated with this movement.

It is thought that mangrove zonation found at the mouth of the Yuna and Barricote Rivers in Samana estuary is changing in response to salinity and freshwater flow alteration. There is anecdotal evidence to support this "observed" change as well as range expansion upriver. The changing diversity and zonation in these mangrove communities may impact habitat for river and estuarine species and nursery grounds critical to viability of many commercially important species. Also, changes in mangrove systems, which contribute to the stability of coral reefs and sea grass beds by protecting them against sedimentation and associated turbidity, may permanently alter the non-estuarine food web found in Samana Bay.

4. Water Dependent Sectors and Resource Use in the Watershed

4.1 Agriculture

In 2000, the proportion of total land area in the country corresponding to farming activities was 55.2 percent (Lizardo, 2003). In terms of water use, agriculture represents 88 percent of total water demand in the country (Lizardo, 2003) of which irrigation accounts for 79 percent (SEMARN, 2001). The Provinces where agriculture has the greatest impact economically include those of the Yuna watershed (La Vega, Duarte, Sánchez Ramírz, and Maria Trinidad Sánchez Provinces). Most of the extension of the Yuna watershed is in the area known as the Cibao Region, which is characterized by low to gentle slops, good soils, and good precipitation.

Major cities in the Central Cibao and Yuna basin include San Francisco de Macorís, La Vega, Moca, and Cotuí.

In the Yuna watershed, the principal crop is rice. More than two-thirds of national rice production comes from the Yuna basin (FAO, 2001). In 2002, 150,000 hectares of land were dedicated to rice in the country overall. There were approximately 94,000 hectares under irrigation, accounting for 35 percent of the total area under irrigation.

The growth of rice production coincided with public investments in irrigation, agricultural credit, and the conversion of native vegetation in flooded and marshy zones to rice paddies. The Yuna River delta was once the most extensive marsh wetland in the country (TRD, 1991). This flood plain was converted to rice and cattle production. The potential for rice production in the Yuna watershed is greater than the other two areas of the country where rice is produced (CEBSE, 1993a). In the North and Northwest, rice production irrigated by the Yaque del Norte already has a very high intensity of production. The region to the south, irrigated by Yaque del Sur lacks infrastructure and results in very expensive production. The area with the greatest potential is the lower Yuna and Nagua area where production intensity is still low and where infrastructure is in place. This area contributes 60 percent of national production (CEBSE, 1993a).

The size of the farming sector in the national economy and in terms of employment has significantly declined in past decades. In 2000, 16.3 percent of the economically active population was working in the farming sector, contrasting with 54.7 percent in 1970 (Lizardo, 2003). The proportion of the population in rural areas has also declined.[5] In 1980 approximately 48 percent of the economically active population lived in the rural area, but by 2000 the percentage was 37.5 percent (Lizardo, 2003). However, rice production has not declined. Area harvested in 1985 was 110,301 hectares. In 2000 it had increased to 129,290 hectares.

Agricultural policies have had an important impact on patterns of production. In general, they have tended to subsidize staple food production to keep prices low for urban consumers. In the Dominican Republic, rice is the single most important source of daily calories, providing 25 percent more than any other crop. Per capita consumption in 2002 averaged 158 pounds, which is more than two times the average in Latin America and the Caribbean, and more than six times the average in the U.S. In 2002, domestic consumption of rice amounted to 1.43 billion pounds.

A consequence of agricultural policies is that crops with positive environmental externalities on the protection of watersheds have been taxed, while farming practices with negative environmental externalities have been encouraged (Lizardo, 2003). For example, rice requires a liberal application of agrochemicals and extensive irrigation, but it is subsidized in the form of trade barriers, domestic pricing and public provision of irrigation infrastructure. One report (Lizardo, 2003) concludes that sustainable agricultural development requires a redefinition of the prevailing pricing and subsidies schemes in order that producers and consumers internalize the positive and negative environmental externalities generated by different farming production systems.

4.2 Mining

Falconbridge Dominicana, a Canadian-owned firm, operates a nickel-iron mine and smelter in Bonao. The Government has a 10-percent stake. The mine at Bonao has been in operation since 1972. In the late 1980s, the Bonao nickel-iron mine was the second largest in the world.

The Government operated a mining operation in Cotuí for 20 years that produced *doré* (an alloy of gold and silver) for export. When it was purchased from a private U.S. company in 1979 it became the largest Dominican-owned company in the country. In the 1980's, the Pueblo

[5] It is important to note that while the proportion of the rural population has declined, the total number of rural inhabitants has not decreased. In 1990 the total population and rural population were 7 and 2.9

Viejo mine, operated by Rosario Dominicano had an annual capacity of 1.7 million ounces of gold and silver. Financial, environmental and minerals processing problems forced the operation to shut down in 1999. Rosario had fully exploited the oxide portion of the deposit. From 1975 to 1999, the mine had produced 5 million ounces of gold and 22 million ounces of silver. The remaining sulfide material contains an estimated 16 million ounces of gold resources, making it one of the largest sulfide gold deposits in the world. The process of exploiting sulfide ores is more expensive and requires different technology.

In 2003, Canadian gold giant Placer Dome signed an agreement with the Government to resume operations at the Pueblo Viejo mine. The company has pledged to invest US$336 million to reactivate the old Rosario mine, in addition to the sum of US$1.5 million per year to be spent on water treatment. The Pueblo Viejo site presents an environmental challenge in the form of acid rock drainage from past operations. Under the agreement, the Government remains responsible for all historic environmental liabilities while Placer Dome will assume responsibility for environmental effects resulting from its operations.

4.3 Tourism in Samana Bay

The tourism industry exploded in the last 15 years and is now the number one source of foreign exchange and one of the top three sources of employment and domestic income in the country. Tourism is important to the economy of Samana Bay, but it is not large beach resort tourism typical of other areas, such as Punta Cana in the East. Samana and the surrounding area are known for its natural attractions such as whale watching (January-March), hiking, and visits by boat to scenic Los Haitises National Park where there are numerous small islets, marine birds, and caves that can be explored, some with Taino (pre-Columbian indigenous population) drawings. The number of visitors who come to see whales has grown from 165 in 1985 to a high of 35,000 in 2000. Samana Bay is one of the best places in the world to see whales. It takes little

million. In 2000, the total population and rural population were 8.4 and 2.9 million (World Bank, 2004).

time to reach the whales by boat and sighting of whales is almost guaranteed. Most of the tourists visiting the Bay come by bus to the town of Samana and stay only for the day. There are no international tourism facilities in the west end of the Bay where the Yuna estuary is located.

4.4 Fishery

In the Dominican Republic, fisheries are small-scale and use simple, traditional methods. The fishery sector accounts for only about 0.2 to 0.6 percent of GNP (CEBSE, 1993a). This is due to the lack of fisheries development strategies, limited investments in the sector, poor marketing structures, and rudimentary fishing technologies. Samana Bay is one of the most important fishing regions in the country. Despite the small size of the fishery sector in the country overall, the shrimp fishery in Samana Bay, specifically in the area of Sánchez, is the most important economic activity to the local community. About 15 thousand families in the Samana Bay area depend on fisheries for their livelihoods (World Bank, 2004). The Yuna estuary in Samana Bay creates conditions that promote a high level of fish productivity. Data from 1991 showed that Samana accounted for 34 percent of fishers (about 2,500 fishers) and 33 percent of fishing boats in the country (Pronatura, 1993). A survey conducted in 1990 showed that 2,947 of a national total of 8,640 fishers are located in Samana Bay (CEBSE, 1993b). Most of the fishers have other sources of income. CEBSE (1994) reports that 27 percent are employed only in fishing and that for 46 percent of fishers, agriculture is the primary secondary source of employment.

A study by Sang et al. (1997) showed the large diversity of the fishery in Samana—178 species of fish, 11 crustaceans and 6 mollusks. The fishery is small-scale and CEBSE (1994) reports that 85 percent of the fishers use dugout canoes 3-5 meters in length known locally as "cayuco." Only 21 percent of these boats have outboard engines. The cayuco is used primarily in the shrimp fishery (*penaeus smithii*). The cayucos are concentrated in the town of Sánchez, which is close to the shrimp fishery in the interior of the Bay. A study of the shrimp fishery found that the fishing fleet of the town of Sánchez is comprised of 317 boats, of which 310 were cayucos with a length from 12-22 feet (Zorrilla et. al., 1995). Sixty-five percent of the Sánchez fleet is powered by outboard engines.

5. The System of Dams, Reservoirs, Irrigation, and Hydropower

In the Yuna watershed there are six dams and another one under construction: Blanco dam, Arroyón dam, Tireito dam, Yuboa dam, Hatillo dam, and Rincón dam. Guaygüí dam is under construction [please provide locational information and size of dam and reservoir]. The three major dams with hydropower stations are the Hatillo (Yuna River), Rincón (Jima River), and Blanco (Blanco River) with installed capacities of 8, 10, and 25 megawatts, respectively. Rincón hydropower station came online in 1978, Hatillo in 1984, and Blanco River in 1996. The nation has an installed hydroelectric capacity of about 460 megawatts, which supplies the country with 28 percent of its electricity demands (US Army Corps of Engineers, 2002).

Hatillo and Rincón are multipurpose dams and hydropower stations; the reservoirs also supply water for municipal, industrial and agricultural needs, and help to prevent cyclic flooding of the lower reaches of the river. Very large quantities of fresh water are available from the Hatillo and Rincón Reservoirs. Hatillo reservoir serves the potable water needs of Cotuí. Rincón reservoir serves the human water needs of Salcedo and San Francisco de Macorís.

Details on the height of dams in the country, reservoir capacity, and hydropower are shown in Table 1. Hatillo Reservoir is the largest in the country. Abt (2002) reports that the Hatillo, Rincón, and Blanco dams have watershed areas of 1,167 km^2, 159 km^2, and 172 km^2, respectively. The capacity of these reservoirs has been greatly reduced by sedimentation—by 19.3 percent in the case of the Rincón Reservoir, and 14.8 percent in the case of Hatillo (IRG, 2001). Accumulated sediments in the reservoirs are estimated at 65 million m^3 for Hatillo and 12.8 m^3 for Rincón (Office of the President, 2002). In the case of the Hatillo dam, the level of observed sedimentation is 33 times greater than what was predicted at the time of construction (SEMARN, 2001). Sedimentation from deforestation and the destruction of watersheds is the greatest threat to the production of hydroelectric power. Massive erosion fills the reservoirs and rapidly wears down turbines and other machine parts. Sedimentation rates of selected dams are shown in Table 2 (IRG, 2001).

Table 1. Hydropower Statistics for Major Dams

Dam	River	Dam Height (m)	Dam Type	Reservoir Capacity (MCM)	Installed Capacity (MW)	Power Generation (GW-h/yr)
Travera	Río Yaque del Norte	80	Earthen	137	96	220
Lopez-Angostura	Río Bao	20	Earthen	4.4	19	120
Jimenoa	Río Jimenoa	14.5	Gravity	0.03	8.6	40
Moncion	Río Mao	120	Rock	369	45	158
Contraembaise Moncion	Río Mao	19	Reinforced concrete	7.6	3.2	15
Hatillo	Río Yuna	50	Earthen	375	8	50
Rincón	Río Jima	54	Gravity	60	10	30
Río Blanco	Río Blanco	43	Gravity	1.1	25	108
Alto Yuna (proposed)	Río Yuna	106	Earthen	65	59	
Sabana Yegua	Río Yague del Sur	76	Earthen	422	12.5	30
Sabaneta	Río San Juan	70	Earthen	63	6.4	25
Las Damas	Río Las Damas	15	Gravity	0.04	7.5	25
Jiguey	Río Nizao	110	Arc	167	98	202
Aguacate	Río Nizao	48	Gravity	4.3	52	208
Valdesia	Río Nizao	78	Buttress	187	54	80

Source: Corporación Dominicana de Electricidad, as listed in US Army Corps of Engineers (2002). Note: Abt (2002) lists power generation for Hatillo as 34, and Rincón as 24.

One of the motivations of watershed management, reforestation projects, promotion of sustainable agricultural practices and establishment of national parks in the Cordillera Central is the realization that public investments in dams, hydropower, and irrigation infrastructure was seriously compromised by rapid sedimentation of the reservoirs. The national extension of protected areas increased from 4.2 percent of the terrestrial area of the country in 1980 to 16 percent in the 90s (Lizardo, 2003).

Table 2. Rates of Sedimentation in Selected Dams

Dam	Sedimentation (m^3/km^2/year)
Sabaneta	1,963
Tavera	2,284
Sabana Yegua	2,644
Valdesia	3,218
Rincón	4,442
Hatillo	4,575

De Janvry et al. (1995) estimated the net economic benefits of changes in upstream land use patterns by exploring three components: the relationship between soil erosion and sedimentation of the Bao reservoir, the length of useful life of the dam, and the unit value of water in terms of electricity production and irrigation (a function of rice production). They find that the recommended practices are privately profitable and generate significant social gains.[6]

Seventy percent of the water from the 14 major dams and reservoirs in the country is destined to the cultivation of rice (Abt, 2002). From 1980 to 2000 irrigated area increased from approximately 178,000 hectares to 275,000 hectares (SEMARN, 2001). Irrigated land represents around 10 percent of suitable land for agriculture and 17 percent of cultivated land (Lizardo, 2003). The demand of water calculated by the watershed area with irrigation infrastructure is equivalent to 13 percent of the total runoff of the country (Abt, 2002). Nationally, the main irrigated crops are rice, plantain, banana, pulses, starchy roots, corn, tobacco and vegetables (Lizardo, 2003). Among these, rice is by far the crop with the most area under irrigation in the country (about 40-50 percent of the area planted in irrigation districts (Abt, 2002)). The Yuna watershed is located in the principal rice zone in the country and it is the principal irrigated crop. The Hatillo and Rincón reservoirs provide irrigation to 40,000 and 6,900 hectares of farmland, respectively (Office of the President, 2002). The Yuna-Camu and Lower Yuna irrigation districts

[6] The Universal Soil Loss Equation was adapted to predict erosion corresponding to the different cropping systems. The erosion for traditional slash and burn conuco (small household agricultural plot) and pasture is enormously high relative to improved conuco practices or national park. They compute total potential erosion in tons/ha/year under average conditions of slope and rainfall as follows: traditional conuco 572; slash and burn pasture 111; improved conuco 35; and national park 8.4.

have 863 km of irrigation canals (Abt, 2002). In the Yuna-Camu irrigation district, there are many irrigation canals that seasonally convey 0.5 to 29 m^3/s. Abt (2002) reports information from INDRHI that shows the area under irrigation and number of users for the Yuna watershed (see Table 3).

Table 3. Irrigated Area and Users by Irrigation District and Zone in the Yuna Watershed

District and Zone	Area (hectares)	Number of Users
Yuna/Camu	33,949	7,113
La Vega	14,442	2,651
Cotuí	13,955	2,532
Bonao	3,034	865
Constanza	2,517	1,065
Lower Yuna	28,730	10,796
Nagua	9,184	2,796
Aglipo	7,806	3,370
Limon del Yuna	7,501	1,590
Villa Riva	4,239	3,040

With 17,909 farmers and 62,678 hectares planted under irrigation, the average irrigated farm size is 3.5 hectares.

Agricultural irrigation is managed through irrigation districts organized by INDRHI. Irrigation fees only cover about 10 percent of the cost of maintenance and operation of irrigation systems and the pricing system does not promote the conservation of water or the development of a market for water (Abt, 2002; Lizardo and De los Santos, 2003).[7] Once the irrigation fee for the irrigation district is established the farmer has to pay by the extension of the irrigated area and not by the volume of water consumed. The fee does not include the costs of the operation and maintenance of the principal canal (Abt, 2002). Since the late 80s, authorities are transferring more control of the operation and maintenance systems to irrigation user organizations (Junta de Regantes) in order to improve water administration (Lizardo and De los Santos, 2003). The World Bank (2004) reports that although the promotion of irrigation user associations is having positive results in terms of water fee collection rates, the level of the fees is not yet covering 25

[7] The cost of water is only 0.5 percent the overall cost structure of heavily protected crops such as rice (World Bank, 2004, p. 12).

percent of the cost of operation and maintenance of irrigation infrastructure. Increasing the contribution of farmers to operation and maintenance is a political hurdle. The country is in the process of passing a new General Water Law and Water Supply and Sanitation Law, which will establish a pricing scheme, oriented to promote a more efficient used of water (INDRHI, 2003a; Lizardo and De los Santos, 2003). However, INDRHI's proposals to change the Water Law have so far been received with great mistrust from the potable water and hydroelectricity operators, which see INDRHI as biased in favor of irrigation users (World Bank, 2004, p. 42).

Current irrigation systems are very inefficient, and only about 18 to 20 percent of the irrigation water is beneficially used to grow crops (IRG, 2001). Abt (2002) reports that the efficiency in irrigated water use reaches 25 percent at best. This inefficiency is due to several factors: canal infrastructure and its state of disrepair, high evaporation rates, the methods used for applying water to crops, the management of the canal system, and the education or skill of the farmers applying the water (US Army Corps of Engineers, 2002). The use of non-appropriate water management in agriculture has caused soil salinity. In 1992, 20 percent of irrigated land presented soil salinity problems (Lizardo, 2003). In 1999 it was estimated that 42 percent of the irrigated areas showed soil salinity and drainage problems (Lizardo, 2003). In the Camu and Yuna River basins, poor drainage is the main problem. Poor water application techniques cause large losses to the agricultural production system, including loss of soil productive capacity from salinization, limitation to the area that can be irrigated due to lack of availability of water, loss of crop productivity due the misapplications of water, water and crops, and higher costs of production.

Abt (2002) conducted cost-benefit analyses of alternatives to current agricultural systems that would be both environmentally and economically beneficial. Based on this analysis, the report concludes that the most important priorities that require attention are 1) setting irrigation fees to reflect the actual value of the resource, 2) economic and environmental studies of the irrigation sector, and 3) establishment of a water quality monitoring system in irrigation districts.

6. Threats to the Quantity, Timing and Quality of Freshwater Inflows and Estuary Health

6.1 Conceptual Model Overview

The biological diversity of Samana Bay and surrounding area, while historically high, is threatened by many anthropogenic sources of stress including agriculture, residential sewage, mining, over fishing, deforestation, and alteration of freshwater inflows through irrigation canals and dams. Recently, thousands of tons of rock ash (fly ash which contains heavy metals and toxins) was placed as land fill along the Bay. Mercury is a major threat from a 16th century galleon that went down in the Bay with a cargo of "quicksilver" to be used in gold extraction. These sources of stress create changes in the salinity structure of the Bay, introduce sedimentation, nutrients, and toxins, and affect species composition (see Figure 6). The precise interactions between these types of stress and estuarine ecology are complex, difficult to model and poorly understood. However, it is known that they cause important and sometimes permanent changes to natural communities, estuarine productivity and resilience, species composition and population, and biodiversity. For instance, Samana Bay has experienced a decline in the catch of shrimp, on which poor communities heavily depend. While there are problems with overfishing, the decrease in catch is largely blamed on high levels of chemical pollution due to upstream agriculture, high levels of heavy metals originating in the mining industry, and sedimentation caused by construction of canals on the Yuna River (World Bank, 2004, p. 19).

6.2 Water Contamination from Rice Cultivation and Other Sources

Surface water quality is contaminated by industry, untreated sewerage and animal wastes, and agricultural nutrients, pesticides and herbicides. A national environmental assessment finds that water contamination is a serious problem in the DR that is growing worse (IRG, 2001). A major source of contamination is the seepage of nutrients into groundwater owning to inadequate sanitation infrastructure (principally sewerage wastewater systems).

In the Dominican Republic 46 percent of pesticides commercialized are considered highly dangerous (Lizardo, 2003). Not all farmers follow the guidance established for application of pesticides. Thus, problems related to the use of agricultural chemicals occur not only for lack of regulations, but also for deficiencies in application methods. Abt (2002) reports that most farmers are not precise in the formulation of insecticides. There are also deficiencies in storage and transport.

SEMARN (2001) reports that the Yuna River carries solid wastes, domestic and industrial liquid waste, animal waste, and agrochemical wastes (chemical fertilizer, pesticide, herbicide and fungicide). Abt (2002) estimated the release of BOD and nutrients (Table 4) and pesticides (Table 5) to the Yuna watershed. Water treatment in the Yuna watershed is limited. The majority of the population uses latrines and septic systems.

Total annual liters of pesticide application in the Yuna watershed by the grade of risk for humans are estimated at 140,407 high risk, 503,350 medium risk, and 14,245 low risk (Abt, 2002). Converting this to intensity of application of pesticides per unit area (liters/km^2), it is estimated that the value is 27 for high risk, 96 for medium risk, and 3 for low risk (Abt, 2002). Based on this analysis, Abt (2002) suggests that a priority for more detailed analysis and possibly stricter regulation is the insecticide Ethoprop (commercial name: Mocap). The United States Environmental Protection Agency has designated Ethroprop as a possible cancer causing substance in humans. Release of Ethoprop (in excess of 9 kgs) in the US must be reported to a local emergency planning committee, established by federal law. The chemical causes significant damage to aquatic ecosystems and is highly toxic to birds, marine crustaceans, and estuarine fish.

Table 4. BOD, Nitrogen and Phosphorus in the Yuna watershed

Source	BOD (kg/day)	Nitrogen (kg/day)	Phosphorus (kg/day)
Residential iquid waste	27,252	2,725	545
Industrial liquid waste	3,038		
Solid waste	37,634	2,214	738
Urban runoff	840	106	32
Agriculture	NA	5,310	442
Non-agricultural runoff	NA	939	125
Animal waste	28,227	4,391	1,141
Total	96,990	15,686	3,023

Table 5. Estimated application of Selected Pesticides in the Yuna watershed (liters/year, except where indicated otherwise)

Pesticide	Liters/year	Primary Use	Risk Class
2-4DAmina	313,667	Herbicide	Moderate risk
Glifosato	8,970	Herbicide	No risk
Paraquat	4,449	Herbicide	Moderate risk
Metaloclor	5,275		
Peretroides	46,989		
Dianizon	3,658	Insecticide	Moderate risk
Metamidafos	135,119	Insecticide	High risk
Ethoprop (liquid formulation)	3,296	Insecticide	Extreme risk
Ethoprop (kgs) (solid formulation)	2,776	Insecticide	Extreme risk
Monocrofotos	1,043	Insecticide	High risk
Metomil	948	Insecticide	High risk
Carbofuran (kgs)	158,850	Insecticide	High risk
Dimetoato	134,587	Insecticide	Moderate risk

The negative environmental impacts of runoff of agrochemicals from intensive rice cultivation throughout the Yuna watershed has been highlighted (e.g. Pronatura, 1993, and TRD 1991) but the effects have not been studied. It is presumed there is a negative impact on the food chain of the coastal ecosystem, eutrophication, contamination of oysters, crabs and shrimp for human consumption, reduced productivity of the Bay's waters, and mortality of bird populations (CEBSE, 1993a).

A study cited in SEMARN (2001) detected agrochemicals in the tissue of oysters that grow on the roots of red mangrove trees in the Yuna delta. A report by the UNDP in 2000 indicates that mollusks in the Samana estuary have bio-accumulated pesticide and organic compounds in their tissues, such as DDT and PCBs (reported in US Army Corps of Engineers, 2002). SEMARN (2001) cites another study that found concentrations of heptchlor, chlordano, aldrin, dieldrin, and DDT in riverbed sediments and bivalves of the Rió Yuna. According to Barzman and Peguero (1995), agrochemical use for rice cultivation in the Yuna watershed is contributing to loss in soil fertility and to increases in pests, weeds, and diseases, which, in turn, require increases in the already high use of the same agrochemicals. They find that 93.5 percent of farmers have increased the application of agrochemicals in the last 10 years because of losses in soil productivity and an increase in the resistance of plant diseases and pathogens.

Contamination from mining operations has not been well studied. It is believed, however, that mining activities (Falconbridge nickel-iron mine in Bonao and the Pueblo Viejo gold and silver mine in Cotuí) release sulfuric acid, mercury and other contaminants into the Yuna watershed and Samana Bay (Bautista and Ginebra, 1996 as cited in SEMARN, 2001). The Office of the President (2002) cites a 1996 study on the quality of water in the Hatillo reservoir, which is in the area of influence of the Pueblo Viejo mine, which finds high levels of iron and nickel. The water released from Hatillo dam is also reportedly highly acidic. IRG (2001) reports that a recent USGS study conducted in small drainages below the Hatillo Reservoir revealed the presence of elevated levels of cadmium, chromium, and other heavy metals. Clearly, these contaminants can have major negative effects on estuary and reef ecosystems, especially in partially closed estuaries like Samana Bay. The presence of mercury in the waters of Samana Bay arriving by the Yuna River was noted as an environmental and human health problem by the conservation group Pronatura over a decade ago (Pronotura, 1993). CEBSE (1994) reports that a preliminary study of Samana Bay showed high concentrations of mercury in the sediments taken from different locations in the Bay. Some samples showed values as high as 7,000 ppm. Detailed studies are needed to determine the origin of this contamination and the ecological impact. As the IRG (2001, p. 17) report states: “A gigantic lack of data on ambient water quality conditions threatens to obscure various threats to human health, aquatic life, and ecosystems from agricultural, industrial, mining, and urban development sources.” It is therefore imperative that environmental authorities begin to develop a program to monitor and analyze water quality parameters in areas at risk (e.g. ports, rivers in agricultural zones, key estuaries).

A country environmental report finds that agrochemicals could be better controlled by both the Ministry of Agriculture and SEMARN through proper incentives and regulations (World Bank, 2004). Recommended measures include: ending subsidized credit for agrochemicals; (ii) enforcing prohibitions on internationally banned agrochemicals; (iii) licensing dealers and various classes of applicators; and (iv) developing an information campaign and public awareness program that educates farmers on the proper use of agrochemicals.

6.3 Assessment of the Impact of Dams on the Yuna River Flow Regime

Across a period of record for a stream gage, natural variations in climatic conditions—especially the timing and amounts of rainfall in a region—have a substantial impact on a river's flow regime. These differences can manifest as variations in the overall volume of water discharged by the river during the year; the size, time of year, and duration of floods or low flow conditions; and the frequency of these types of flow conditions within or across years. A number of human activities can change one or more of these natural characteristics of a river's flow regime, including land use conversion, construction and operation of dams, and ground water pumping or direct surface water diversions.

Using pre- and post-dam gauging data, we assessed the influence of the Rincón and Hatillo dams on the Yuna's flow regime and consequently the freshwater inputs to Samana Bay (Appendix 2). The data illustrate that the post-dam period has been generally wetter than the pre-dam period, with consistently greater average monthly flows. While flows between January and March (dry season) roughly doubled over the pre-dam period, increases in flow during other months have been far less dramatic. However, overall the influences of the dams on freshwater inputs to Samana Bay are not clearly discernable from these data and the higher levels of flow in the post-dam period could be the result of other causes such as ongoing changes in land use, irrigation or simply differences in climate across the two periods.

6.4 Changes to Freshwater Inflows: Proposed Construction of Dam at Piedra Gorda, Bonao

Rice production is dependent on a high level of agrochemicals, which eventually find their way to Samana Bay, and is also dependent on an extensive irrigation system. The size of the irrigation system and its inefficiency has already been documented. IRG (2001) reports that the growth of irrigation over the past 20 years has reduced normal dry season water flows in the Yuna watershed, affecting downstream freshwater habitats.

One of the threats to freshwater inflows is an expansion of the existing system of irrigation with the construction of another dam in the upper Yuna River. INDRHI's original masterplan for the Yuna watershed from the 1970's included plans for a dam in the upper Yuna River at Piedra Gorda, Bonao. In April 2003, the administration of President Mejia's reported it was concluding plans to start construction of a multipurpose hydroelectric dam at this location. The dam proposed by INDHRI would be located below the confluence of the Yuna River and Blanco River, about 2 kilometers upstream from the town of Los Quemados.

There is concern that the Hatillo dam is not functioning adequately, since it overflows about three times a year. The new dam would provide water for industrial, municipal use and irrigation, and would help avoid frequent floods in the important rice growing zones of the lower Yuna River. It would transfer a large amount of excess water that the Hatillo dam cannot store to the dam at Rincón by tunnel and canal. The canal would provide an estimated average of 10.3 m^3/s flowing to Rincón dam about 20 km north. The President's web page says that 525 m^3 of water per year would be diverted to the Rincón dam (www.presidencia.gov.do/ingles/Noticias-2003/Abril accessed February 5, 2004). This would supply water to several major cities in the Cibao (Bonao, San Francisco de Macoris, Moca, Salcedo, Tenares and Villa Tapia). It would extend the area of irrigation provided by the Rincón dam by about 13,000 hectares (along the

Jima and Camú riverbanks and other farming zones in La Vega and San Francisco de Macorís). It would also allow the addition of another turbine with a 10 MW capacity at Rincón dam (providing an estimated annual 21 GWH) (CDE, www.hidroelectrica.gov.do accessed February 5, 2004).

There was concern that the dam would reduce the flow of water needed downstream. INDHRI was unable to counter this concern and provide communications and outreach to local stakeholders. As a consequence the development proposal has been dropped for the moment.

6.5 Deforestation and Sedimentation

Deforestation is recognized as one of the most significant causes of alteration of natural habitat in the country. Eighty percent of the country was covered in forest in 1900, 69 percent in 1940, and 27.5 percent in 1996 (SEMARN, 2001). An estimated 53 percent of the total land area is best suited for forest cover. However, only an estimated 14 percent of the surface area is covered in forest (US Army Corps of Engineers, 2002). Of that amount, only one-third of the forests are undisturbed by fire or slash and burn agriculture. The causes of deforestation are cutting for fuel wood, charcoal production, and unsustainable agricultural practices. The Dominican Republic is mountainous, and much of the soil is poor, shallow, and easily eroded.

The key impacts of deforestation on hydrological cycles and resources include:

- A decrease in infiltration and recharge of aquifers, causing drier than expected soil conditions
- An increase in the volume and velocity of surface runoff
- A decrease in uniformity of stream flow (very low during dry periods and more frequent and intense flooding during wet periods)

These changes also lead to increased sedimentation of streams and rivers. Studies of seven deforested basins showed a loss of surface soil of 100-500 tons/ha/yr (Alvarez, 2000). It is estimated that 86 percent of the surfaces of the country’s drainage basins have problems of degradation (Alvarez, 2000). Some of the watersheds where environmental degradation is most serious are the Yaque del Norte, Nizao and the Yuna. We have not seen any studies on the impacts of sedimentation on the estuary. The Hatillo and Rincón reservoirs are trapping sediment from the upper watershed. However, periodic flooding releases large quantities of sediment to the lower Yuna and Samana Bay causing irrigation canals in the lower Yuna irrigation district to be obstructed (Office of the President, 2002). Following flooding, distinct sediment plumes can be observed in the southwest portion of the Bay of Samana (such as following the flooding that occurred at the end of November 2003).

Adequate freshwater inflows are important to most marine and aquatic systems at the saltwater-freshwater interface. For example, it can be important to flush the salts in mangroves. Alterations in flow rates can destroy marine communities. Sedimentation can cover marine communities that depend upon clear water. Seagrass beds and coral reefs are two such communities threatened in this manner.

In the last decade the problems of deforestation have abated. By the end of the 1990s thee is evidence that the land area under forest cover was greater than that of 1980, suggesting that a recovery was occurring (IRG, 2001). Reasons for the stabilization and recovery of forests include (IRG, 2001):

- Migration of rural residents, especially hillside agriculturists, to the cities
- Reforestation and natural resource management programs
- Expansion in the number and size of protected areas
- Reduced taxes on the importation of low cost food commodities which, in turn, contributed to a reduction in steep slope subsistence agriculture
- Subsidized bottled cooking gas which, in turn, virtually eliminated the demand for charcoal (charcoal consumption dropped from 1.6 million sacks in 1982 to 26 thousand sacks in 2000)

6.6 Overfishing

Overfishing and destructive fishing practices are affecting the health of the Samana Bay estuary. Over exploitation has reduced catch of shrimp (*Penaeus schmitti*) and various estuarine fish significantly. The fishery in Samana Bay is artisanal, using methods of cast net and gill net (Silva and Aquino, 1993; Aquino and Silva, 1995). One study found that the number of fishers using cast nets and gill nets to be about equal (Zorrilla, et. al., 1995). The growing length of nets and increasing small size of the mesh has resulted in smaller and smaller average size of caught fish. It was reported to the site reconnaissance team that some of the gill nets are so long they cross the bay. To give a sense of the impact of net fishing, a study about a decade ago determined that there were about 42 kilometers of nets in a fishing zone 17 kilometers wide (Zorrilla, et. al., 1995). The prohibition of gill nets has been suggested as a way to diminish pressure on the shrimp fishery (Zorrilla, et. al., 1995). Another net used is a drag net known as “licuadora” (“blender”), which causes serious damage to marine habitat by destroying the natural stratification of sediment and creating large amounts of turbidity (Sang et al., 1997). There is no program of training and technical assistance directed toward the fishing sector.

Silva and Aquino (1993) and Aquino and Silva (1995) found that the number of fishers in Samana Bay had been increasing by 70 per year. From 1984 to 1990, the number of fishers grew from 1,197 to 2,512 (CEBSE, 1994). SEMARN (2001) reports government data on fish catch of key species from Samana Bay for 1986 and 1997. Three fisheries are distinguished: estuarine, sea grass and coral reef, and oceanic. Among these, catch of the oceanic fishery increased, the fishery around coral reef and sea grass dependent species remained the same (although with large changes in the types of fish caught), and the estuarine fishery declined significantly from 1,420 tons to 449 tons (Table 6). As a result of the decline in the abundance of other estuarine fish, shrimp has risen from eighth place in terms of tons of catch (tons) to second place. IRG (2001) reports that another study prepared for CEBSE indicated a drop in fisheries production from the Samana estuary of 1.86 tons per km^2 to 0.48 km^2 from 1980 to 1994. The continued over exploitation of the Bay's fishery could lead to the disappearance of the fishery as a valued economic activity for communities such as Sánchez.

Table 6. Estuarine Fish Catch in Samaná Bay over the period 1986-1997 (tons)

Common Name	Species	National Office of Statistics (1986)	Secretary of Agriculture (1997)
Machuelo (Atlantic Thread Herring)	Opistonema oglinum	306	188
Sábalo (Tarpon)	Megalops atlanticus	280	27
Lisa (Mullet family)	Mugil lisa	150	59
Corvina (Reef Croaker)	Odontiscion dentex	127	14
Mojarra (Yellowfin Mojarra)	Gerres cinereus	108	12
Macabí (Bonefish)	Albula vulpes	103	16
Ostión (Mangrove Oyster)	Cassostrea rizophorae	99	6
Camarón (Shrimp)	Penaeidae	94	79
Robalo (Bonefish)	Centropomus spp.	65	24
Cangrejo (Blue Crab)	Callinectes sapidus	60	14
Machete (Atlantic Cutlassfish)	Trichiurus lepturus	29	9
Total		1420	449

6.7 Aquaculture

At present, there is little aquaculture development on the lower Yuna. However, the Directorate of Fisheries in the Sub-Secretary of Coastal and Marine Resources with the Dominican Agrarian Institute has a small shrimp aquaculture development project near the town of Sanchez. Approximately 45,000 m^2 of land has been provided by the State where 18 tanks will be placed when the equipment arrives. A cooperative will operate the facilities. The objective of this project is to provide alternative livelihoods and reduce pressure on the shrimp fishery in the Bay.

6.8 Other Threats

SEMARN (2001) reports several other types of impacts to water quality and flow of the Yuna River. They include introduction of exotic species, extraction of sand and gravel, elevated water temperatures and hydrocarbons. Sand mining, principally at river mouths, but also at any location along rivers is a serious problem in the Dominican Republic despite the fact that it is prohibited. On the Yuna River, sand is mined from the riverbed, altering river bathymetry and flow dynamics. Sand mining was observed during the reconnaissance field trip. The reconnaissance team was told that mining of sand from the riverbed is one of the reasons that the Blanco reservoir filled up.

There is also proposed construction of a new international airport (Samana International Airport) located at the Western end of Samana Bay. We were told that it would be constructed on an area of approximately 500 hectares that was formerly mangrove forest. Much of the current soil would need to be removed and replaced with thousands of tons of rockier, more suitable soil.

7. Governance

7.1 Watershed Governance

Although the Dominican Republic has institutions that have conducted many studies and that have experience in management of watersheds and coastal areas, the two sectors (coastal and watersheds) have traditionally operated in isolation and there is not a concept of integrated watershed management from mountains to coast (SEMARN, 2001). Generating local and national development benefits are the priority of water projects such as dams, canals, and river alterations. Hydrologic projects do not consider the impacts on other regions of the watershed, nor the importance of freshwater flows to estuaries. SEMARN (2001) notes that phrases such as “que ni una gota vaya al mar” (that not a single drop of water should go to the sea) appear in draft legislation concerning water resources and are implicit in much of the actual regulations. The web page of the office of the President says that the proposed upper Yuna dam is “designed to keep the Yuna River’s more than one billion cubic meters water from being wasted into Samana Bay each year” (CDE, www.hidroelectrica.gov.do accessed February 5, 2004).

Extensive experience with projects and programs focused on the management of watersheds and soil and water resource conservation is shown by the following list prepared by ONAPLAN (2000) for the Convention on Desertification:

Executing Institution	Objective	Financial Source	Situation
Management and conservation of natural resources in the Watershed of the upper Watershed of the Río Yaque del Norte. Sub-Secretary of Natural Resources (SURENA)	Management and conservation of natural resources of the upper watershed and improvement in the living conditions of the local population.	RD$115,000,000. German Bank and Dominican Government	Initial phase
Integrated study of the watershed of the upper Río Yuna. Secretary of Agriculture (SEA)	Collection of information on natural resources with the goal of providing guidance on protection, appropriate use and sustainability in the area	RD$ 133,356. Dominican Government	Pre-investment
Pilot management plan of the watershed of the Río Mao. INDRHI	Similar to those of the Yaque del Norte program. Río Mao is part of the upper watershed of the Yaque del Norte	RD$12,000,000. Dominican Government	Final phase
Watershed management of the Río Blanco, Yuna and Camú. INDRHI and Plan Quisqueya Verde	Management and conservation of natural resources with an emphasis on reforestation of the watershed	Dominican Government	In execution
Integrated management of the watershed of the Río Las Cuevas (Yaque del Sur). INDRHI and Plan Quisqueya Verde	Protection of the watershed of the Sabana Yegua dam. Focus on control of soil erosion and employment generation.	Dominican Government	In execution
Integrated management of the watershed of Río Panzo (NEYBA). INDRHI and local Communities	Reforestation, organic farming, training, capacity building and improved water resource use.	World Vision	In execution
Reforestation of the upper watershed of the Río Nizaito. INDRHI, Plan Quisqueya Verde, Fundación Prodesarrollo de la Comunidad de Paraíso	Watershed protection, reforestation and preliminary work for a large project on Integrated Management of the Watershed of Río Nizaito	Financed by the Government of Taiwan	Pre-investment
Study of the Watersheds of Artibonito, Masacre and Pedernales. INDRHI.	Description of the watershed situation—water, soil, flora, fauna and communities—with	US$1,000,000	In execution

	the goal of restoration of degraded soil and conservation management		
Conservation management and productivity of the water and soils of the runoff watersheds of the Río Artibonito, Masacre and Pedernales. INDRHI	Improved agricultural production and natural resource protection of the three watersheds	US$10,000,000	In execution
Macasías project. HELVETAS	Forestry plantations and soil conservation in the watershed of the Río Macasías	US$1,200,000	In execution
Project on management of Irrigated land and watersheds (PROMATREC). INDRHI, Utah State University	Restoration of irrigation systems of the Yague del Sur, Nizao and Yaque del Norte	RD$854,000,000	In execution
AGLIPO II Project. INDRHI	Restoration and extension of irrigation systems in the Provinces of María Trinidad Sánchez and Duarte	RD$854,000,000	In execution
Project on irrigation and watershed management. INDRHI	Irrigation infrastructure improvement and watershed management	US$27,000,000 Word Bank	Completed

Source: ONAPLAN (2000)

The Dominican Republic is currently in a period of consolidation of legal frameworks and regulations that govern the environment and natural resources. The Secretariat of the Environment and Natural Resources (SEMARN) was established in late 2000 when the Law of the Environment and Natural Resources was approved (Law 64-00). This provides an opportunity for enhanced planning, management and control of water, soil, forests, coastal and marine resources and environmental management. Previously, the agencies that comprise SEMARN were in separate parts of the government. The secretariat, under overall direction of a cabinet level secretary, is organized into five sub-secretariats: Environmental Management, Soils and Water, Forest Resources, Protected Areas and Biodiversity, and Coastal and Marine Resources. These sub-secretariats are further divided internally into appropriate directorates and departments. Unfortunately, SEMARN is not located in a single building, and its sub-secretariats are scattered around Santo Domingo in different government office buildings.

The harmful effects of a wide array of incoherent and often conflicting laws, decrees and institutions still persists (SEMARN, 2001). The Dominican Republic has numerous water laws[8], but they do not correspond to a global scheme and need to be consolidated. There is no comprehensive water policy or comprehensive law concerning water resources, water development projects do not necessarily have watershed components, and water and coastal management are not integrated. Decisions that affect water supply and water use are spread across many government agencies that operate independently. The numerous laws and lack of appropriate regulations result in a low level of compliance (SEMARN, 2001). Recommendations for earlier studies include: establish a national water law, form a national water commission, form a water resources council, form task forces to address water resources issues, and conduct comprehensive water resources evaluations (US Army Corp of Engineers, 2002). Many of these recommendations are being acted on. For example, a draft comprehensive water law has been prepared (INDRHI, 2003a). As noted earlier, a type of plan for the Yuna watershed was prepared some three decades ago. In meetings in April 2004, we were told that INDHRI wants to update the masterplan and unsuccessfully applied to the Japanese international development agency for external funding to support that work in the early 90's.

Institutional capacity to implement laws and manage water resources is a constraining factor. A report on watershed and coastal management summarized the constraints that confront public sector institutions (TRD, 1991).

- Lack of continuity of agency leadership due to the system of placing political appointees in mid and upper level positions
- The assignment of public employment according to political loyalty rather than merit
- A critical lack of resources and funds to actually implement activities and projects
- Poor compensation for public employees
- A shortage of trained and technically competent technicians

[8] Water regime legislation includes Law 5852 of 1961, Law 487 of 1969, Law 126 of 1980 and Law 64 of 2000.

- Unclear or overlapping functions with other agencies
- Lack of mechanisms for coordination both within and among agencies
- A sense that planning is futile as decision making is highly centralized

Many institutions are responsible for carrying out activities related to the regulation of water, but there is little coordination among them (Abt, 2002). Some of the key government agencies responsible for management of water resources in the watershed of the Yuna River are the National Institute of Hydrological Resources (INDRHI), the National Institute for Potable Water and Sewage Systems (INAPA), and the Dominican Electric Corporation (CDE). INDRHI is an agency within SEMARN whose primary responsibility is managing irrigation systems throughout the country. INAPA provides sanitary sewer service and drinking water for communities. The Dominican Electric Corporation (CDE) is responsible for hydropower.

Local associations called the Junta de Regantes (irrigation user organizations) manage irrigation water in many areas. Law 5852 of 1962 and Regulation 2588 of 1984 gave INDRHI the mandate to gradually delegate the operation and maintenance of irrigation systems to the Boards of Regents in irrigation districts. The process of delegation began in 1987. These associations are elected among farmers that are served by a common irrigation outlet. In general, when under government control, only 15 percent of the fees for water supply were collected; these associations generally collect 60 to 85 percent of the fees (IRG, 2001). Under the management of the Junta de Regantes, and their success in collecting fees, the canals are generally better maintained, and water loss prevention has been promoted among users (US Army Corps of Engineers, 2002). Abt (2002) notes that a principal achievement of the Junta de Regantes is more efficient water use as a result of greater equity in the delivery of water supplies and reduction of conflicts between producers and INDRHI authorities. Some Junta de Regantes are also able to buy modern water management equipment and offer scholarships for members to study water management technology.

None of the Juntas de Regantes are involved in watershed management activities or environmental monitoring. However, Abt (2002) reports that SEMARN is promoting policy that would convert watersheds in regional development units and the development of watershed authorities in which the Juntas would play an important role.

Lockwood (2001) observes that within INAPA there is a general acceptance of the integrated, community participation approach to implementation of rural water supply and sanitation projects. USAID funded a pilot project in Hato Mayor Province to develop a model approach to community participation with INAPA. The “total community participation” approach is designed to maximize the role and responsibilities assumed by communities in the planning, design, construction, and management of their water supply systems.

The Dominican government structure is very centralized with the base of power in Santo Domingo. Municipal governments have long been politically marginalized and do not have a favorable legal structure for exercise of authority or for creating a consistent revenue stream (Lockwood, 2001). As part of a national initiative to increase decentralized governance, the administration of President Fernández initiated reforms to strengthen municipalities and reduce their dependence on a politicized system of revenue allocation. A significant milestone was achieved in 1997 with passage of a law ensuring municipal governments a fixed 4 percent of the national budget. The administration of President Mejía raised the municipal allocation to 5 percent, but legislation to enlarge the range of competencies of municipal governments and to increase management capacity at local levels has been bogged down in the Dominican Senate (Lockwood, 2001). Municipal governments have a long way to go before being in a position to take on delivery of additional local services, such as long-term support for community-managed water supply systems (Lockwood, 2001).

Finally, we note that watershed management and research in the mountains that are the source of the major river systems, including the Yuna, have improved significantly with the designation of national parks, government programs in sustainable land use (such as Plan Sierra and Plan Quisqueya Verde) and NGO initiatives (such as Moscuso Puello and The Nature Conservancy in Valle Nuevo).

7.2 Coastal and Marine Governance of Samana Bay

The Dominican Republic does not have integrated coastal management legislation or policy. The Secretary for the Environment and Natural Resources has several offices and Sub-secretaries directly related to coastal and marine governance: for example, the Directorate of Fisheries and the Directorate of Conservation and Management in the Sub-Secretary of Coastal and Marine Resources, and the Sub-Secretary of Protected Areas and Biodiversity. The Sub-Secretary of Environmental Management is responsible for conducting Environmental Impact Assessments. Decree 531 in 1990 established the requirement that investments in the coastal zone must be preceded by Environmental Impact Studies. However, it was not until the Law of the Environment and Natural Resources (Law 64-00) was approved that the national system of EIA's found an institutional home and EIA's became mandatory. Law 64-00 states, "Planning of national, regional, and provincial development of the country must incorporate the environmental dimension through a dynamic, permanent, participatory, and concerted process among the different entities involved in environmental management." The new environmental law also provides an enhanced role for municipalities in management of environmental matters at the local level. IRG (2001) reports that both municipal authorities and senior Secretariat officials are enthusiastic about this legislative endorsement. However, the local governments require considerable institutional development assistance to effectively carry out their new mandate.

In 1993 the National Office of Planning (ONAPLAN) and a local conservation NGO completed a preliminary diagnosis of the national coastal and marine zone (Pronatura, 1993). From 1996-98 ONAPLAN hosted a UNDP/GEF project on conservation of coastal and marine biodiversity. In the late 90's, the Sub-Secretary of Natural Resources in the Secretary of Agriculture also sponsored a marine and coastal environmental program, including a 1999 study on Integrated Management of Coastal Resources in the Dominican Republic, with an Emphasis on Key Tourism Areas.

The UNDP/GEF project included Samana Bay. There have been many other conservation projects focused on the Samana Bay region as well, many of which have centered around or involved the Center for the Conservation and Eco-Development of Samana Bay and its Surroundings (CEBSE). CEBSE is a non-profit organization created in 1991. The governance strategy promoted by CEBSE is to involve community organizations and resource users in the planning and management of natural resource use in coordination with government institutions and the private sector. Co-management strategies for fisheries and tourism have been primary areas of focus. The geographic scope of CEBSE includes the Bay of Samana, including the Yuna river delta, the karstic region of Los Haitises National Park, and the coastal plan of Sabana de la Mar – Miches.

CEBSE has had many partnerships with external donors and organizations. For years, the U.S.-based Center for Marine Conservation (now Ocean Conservancy) worked with CEBSE to advance community-based outreach and planning, research, and strategies for tourism and fisheries development. From 1996-2000, CEBSE was part of a training program with the Caribbean Natural Resources Institute (CANARI) and the Swiss Development Organization (HELVETAS) on co-management of natural resources.

Some of the key governance outcomes to date for Samana Bay include:

- Integrated Management Plan for the Samana Region (CEBSE, 1996)
- Tourism and Fisheries Development Strategies
- Proposal for designation of Samana Bay and it surroundings as a biosphere reserve
- Implementation of co-management plan for whale watching

8. Conclusions

This profile attempts to pull together the current state of knowledge on the Yuna watershed and Samana Bay. However, there may be sources of data and information that have been missed, and there are certainly basic gaps in knowledge that we will need to fill in the next months of this project through limited field work. Our goal is to construct a sufficiently accurate profile of the Yuna watershed and Samana Bay that can be used as a basis to develop plausible future scenarios and an action agenda.

Our review of the literature and meetings to this date suggest that the key issues in terms of proposed or likely changes to freshwater flow, pulsing and quality to Samana Bay are (see Figure 7):

- Reduction in freshwater inflows due to withdrawals for agricultural and municipal use during the dry season, with resultant impacts on salinity distributions in the estuary and associated shifts or losses in biological resources (particularly mangroves)
- Increased flooding due to deforestation, with resultant increases in soil erosion from hillslopes and channels and sedimentation in the estuary, with associated losses of oyster beds, seagrass beds, and shrimp production and changes in the distribution of various mangrove species
- Increases in chemical pollution from agricultural and mining runoff, with resultant decreases in shrimp, crab, and fish production and increases in human health risks due to consumption of this seafood
- Overfishing impacts on shrimp and fish populations

Given these issues, some of the major stakeholders in the watershed are farmers (use of water and agrochemicals), the mining industry (polluted runoff), and fishermen. Major stakeholders dependent upon a healthy estuary include fishing families, the tourism industry, and environmental interest groups.

These are not necessarily the watershed and estuarine issues that are on the top of the local agenda. At the time of our reconnaissance trip the main issue in the media concerned the dumping of rock ash from Puerto Rico and the United States in Samana Bay and Manzanillo Bay. Since then, the reform of the Protected Areas Law has been the main national environmental issue.

To validate or further develop these conclusions, we have identified the following priorities for additional fieldwork or investigation in this project:

- Field mapping of biological resources and habitats in the estuary
- Data on bathymetry of Samana Bay, salinity structure, and mangrove change analysis over the past three decades to better understand the ecology of the Bay and impacts of alterations to freshwater inflows on conservation targets
- Analysis of existing information on groundwater flows in the Samana Bay area to improve our knowledge of the hydrology of the estuary
- Further analysis of the impacts of different freshwater flow regimes (seasonality, dry and wet season, peak and low flow) on the ecology of Samana Bay
- Analysis of precipitation trends to verify whether rainfall in the post-dam period has been significantly greater than during the pre-dam period
- Further analysis of the river flow data, to see whether any trends in dry season (June-September) monthly flows are detectable
- Carefully review IRG (2000) report to better understand their conclusions about reduced dry season flows
- Obtain information about the operating plan for the proposed Piedra Gorda dam to evaluate its likelihood for impacts on river flows in the Yuna

- Obtain information on the operating plan for Hatillo Dam to evaluate its impacts on daily river flow fluctuations
- Consultations with government and stakeholders to better identify scenarios of likely changes to freshwater inflows and to better understand the perceptions and concerns of stakeholders
- Consultations with government and stakeholders to assess the potential for forming a watershed-wide council or commission to advance integrated watershed management
- Develop additional socioeconomic and demographic profiling and projections of demographic and economic changes in the future that might affect the river and estuarine resources

References

Abt, *Diagnóstico Ambiental Y Análisis Económico*. Informe Final, Volumen 6, Capítulo 10: Agricultura. Elaborado por Abt Associates, Inc., con la Secretaría de Estado de Medio Ambiente y Recursos Naturales. Proyecto de Potíticas Nacionales de Medio Ambiente, 240 pp. (http://www.ambiente.org.do/PDF_finales/informes_ef/Vol1ResumenEjecutivoAbtAssociatesInformeFinalDiciembre2002.pdf)

Alvarez, M., The Dominican Republic and Sustainable Development, in *Sustainable Development: Latin American and Caribbean Perspectives*, Economic Commission for Latin America and the Caribbean, Santiago, Chile, pp. 107-117, 2000 (http://www.un.org/esa/sustdev/publications/sdlac_perspective_book.pdf, accessed February 7, 2004)

Aquino, C. and Silva, M., *La Pesquería Marina en la Costa Sure de la Bahía de Samaná (Sabana de la Mar y Miches), República Dominicana: Estudio Básico*, CEBSE, Santo Domingo, 28 pp.

Barzman, M., and Peguero, B., Caracterización del Marco Institucional y su Influencia en el Uso de Agroquímicos y en la Sostenibilidad de la Producción de Arroz Irigado en la República Dominicana. Informe para CEBSE y la Fundación Winrock International, 22 pp., 1995 (www.nwaeg.org/rd98.doc, accessed February 16, 2004)

Bautista, J., and Ginebra, C., Evaluación Rápida de la Contaminación Ambiental en el Municipio de Sánchez y el Distrito Municipal de Las Terranas de la Provincia de Samaná. Reporte técnico de Pro-Ambiente J&M, S.A., 200 pp., 1996.

CEBSE, "Propuesta Descriptiva para la Implementacion de la Reserva de Biosfera Bahia de Samana y su Entorno," 77 pp., Marzo 1993.

CEBSE, "La Pesquería Marina en la Provincia de Samaná, República Dominicana: Estudio Básico," Center for the Conservation and Ecodevelopment of the Samaná Bay and its Surroundings and the Center for Marine Conservation, Samana, Dominican Republic, December 1993

CEBSE, "Caracteristicas Socio-Economicas y Culturales de las Comunidades Humanas Alrededor de la Bahia de Samana," Center for the Conservation and Ecodevelopment of the Samaná Bay and its Surroundings and the Center for Marine Conservation, Samana, Dominican Republic, February 1994.

CEBSE, Plan de Manejo Integrado para la Región de Samaná. Center for the Conservation and Ecodevelopment of the Samaná Bay and its Surroundings and the Center for Marine Conservation, Samana, Dominican Republic, 90 pp., June 1996

De Janvry, A., Sadoulet, E., and Santos, B., Project Evaluation for Sustainable Rural Development: Plan Sierra in the Dominican Republic. *Journal of Environmental Economics and Management*, Vol. 28, pp. 135-154, 1995.

FAO, http://www.fao.org/ag/agp/agpc/doc/riceinfo/america/domrep.htm, accessed February 10, 2004)

INDRHI (a), Proyecto Ley de Aquas. Instituto Nacional de Recursos Hidráulicos, 144 pp., February 2003 (http://www.indrhi.gov.do, accessed February 16, 2004)

INDRHI (a), Proyecto Ley de Aquas. Instituto Nacional de Recursos Hidráulicos, 144 pp., February 2003 (http://www.indrhi.gov.do, accessed February 16, 2004)

INDRHI (b), Inundaciones Cuencas Yaque del Norte y Yuna. Instituto Nacional de Recursos Hidráulicos, 45 pp., November 2003 (http://www.indrhi.gov.do, accessed February 16, 2004)

IRG, *Dominican Republic Environmental Assessment*. International Resources Group, Ltd., USAID Contract No. PCE-I-00-96-00002-00, Santo Domingo, September 2001.

Jorge, M., Developing Capacity for Coastal Management in the Absence of the Government: A Case Study in the Dominican Republic. *Ocean and Coastal Management*, Vol. 36, No. 1-3, pp. 47-72, 1997.

Laba, M., S. Smith and S. Degloria, Landsat-based Land Cover Mapping in the Lower Yuna River Watershed in the Dominican Republic. *Int. J. Remote Sensing*, Vol. 18, No. 14, pp. 3011-3025, 1997.

Lizardo, M., *National Report: The Dominican Republic*. Roles of Agriculture Project, International Conference, FAO, Rome, Italy, October 2003 (http://www.fao.org/es/ESA/Roa/ROA-e/case_studies-e.htm, accessed February 7, 2004)

Lizardo, M., and De los Santos, J., *Farming Sector Incentive Framework During the 90s in the Dominican Republic*. Roles of Agriculture Project, International Conference, FAO, Rome, Italy, October 2003 (http://www.fao.org/es/ESA/Roa/ROA-e/case_studies-e.htm, accessed February 7, 2004)

Lockwood, H., *Operations and Maintenance Strategy for Community-Managed Rural Water Supply Systems in the Dominican Republic*. Environmental Health Project, USAID, 37 pp., October 8, 2001.

Lopez Ornat, A., Editor, *Strategies for Sustainability: Latin America*. IUCN, 1996.

Office of the President, *Diagnóstico de Situación de los Recursos Agua, Cobertura Vegetal, Suelos y Marino Costeros y su Relación con las Amenazas Naturales*. Secretariado Técnico de la Presidencia, Unidad Ejecutora Sectorial del Sub-Programa de Prevención de Desastres, Santo Domingo, 68 pp., Mayo, 2002 (http://www.uespmr.gov.do/comp_1/mapas_agv.htm, accessed April 27, 2004)

ONAPLAN, *Informe Nacional de la República Dominicana sobre la Implementación de la Convención de Lucha contra la Desertificación y la Sequia*. Document prepared for the fourth Conference of Parties, Oficina Nacional de Planificación, Santo Domingo, April 2000 (www.unccd.int/cop/reports/lac/national/2000/dominican_republic-spa.pdf accessed February 16, 2004)

Pronatura, *Diagnóstico Preliminar Integrado de la Zona Costero Marina de la República Dominicana*, Tomo 1, Oficina Nacional de Planificación, January 1993.

ReliefWeb, *Dominican Republic: Floods Information Bulletin No. 2/03*. (http://www.reliefweb.int/w/rwb.nsf/0/90b58b9681e42366c1256def003cf2c9?OpenDocument, accessed February 10, 2004)

Sang, L., León, D., Silva, M., and King, V., *Diversidad y Composición de los Desembarcos de la Pesca Artesanal en la Región Samaná*. Proyecto de Conservación y Manejo de la Biodiversidad en la Zona Costera de la República Dominicana, GEF/PNUD/ONAPLAN, 52 pp.

SEMARN, *Gestión Ambiental para el Manejo Integrado de Cuencas Hidrográficas y Áreas Costeras en Pequeños Estados Insulares del Caribe*. Reporte final de la República Dominicana, Secretaría de Estado de Medio Ambiente y Recursos Naturales, Subsecretaría de Gestión Ambiental, Septiembre, 108 pp., 2001.

Sherman, R., Digitized Maps of Samaná Bay Mangroves 1959-96 (GIS database at 1:20,000 scale). Final project report, UNDP/GEF, University of Cornell, 5 pp., 1996.

Silva, M. and Aquino, C., *La Pesquería Marina en la Provincia de Samaná, República Dominicana: Estudio Básico*, CEBSE, Santo Domingo, 26 pp., 1993

TRD, *Intensive Survey of Rural and Urban Activities Impacting Water and Coastal Resources*. Tropical Research and Development, Inc. for USAID/DR, 113 pp., January, 1991.

US Army Corps of Engineers, *Water Resources Assessment of the Dominican Republic*, Mobile, Alabama, June 2002 (http://www.sam.usace.army.mil/en/wra/DominicanRepublic/DominicanRepublic.html, accessed February 6, 2004)

World Bank, *Environmental Priorities and Strategic Options: Country Environmental Analysis*, World Bank, Washington, D.C., June 29, 2004, 50 pp.

Zorrilla, T., Balbuena, E., Casilla, M., "Situación Actual de la Pesquería del Camarón Blanco en Sánchez, Samaná," Thesis for a degree in Biology, Universidad Autonoma de Santo Domingo, August 1995.

Meetings and Contact Information
Reconnaissance Trip, April 13-16, 2004

<u>USAID/Dominican Republic</u>

Odaliz Perez, Environment Coordinator, USAID/DR
Tel: 221-2171 ext. 247
Fax: 221-6565
Email: operez@usaid.gov

<u>INDRHI (Instituto Nacional de Recursos Hidráulicos/National Institute of Hydrological Resources)</u>

Raúl Perez, Director of Planning and Special Projects
Tel: 532-3271 ext. 3200
Fax: 508-2471

Agustina Garcia, Water Monitoring Team

Ramon Santana, Environmental Department

Felipe Vicioso, Head of Environmental Management
Tel: 532-3271 ext. 3230
Fax: 508-2471
Email: Rednamacrd@hotmail.com

Antonio Ortiz, Departament of Hydrology
Cell: 707-4925
Tel: 532-3271 ext. 3478
Fax: 508-2471
Email: Ortiz_mena@hotmail.com

<u>Ministry of Environment and Natural Resources</u>

Olga Luciano, Director of Planning Office
Tel: 472-1194
Fax: 472-1198
Email: Olga.Luciano@codetel.net.do

José Ramirez, Sub-Secretary of Soils and Water
Tel: 547-3888
Fax: 547-2185 ext. 2204
Email: suelo.aqua@codetel.net.do

Igor Bucarelli M., Sub-Secretary of Coastal and Marine Resources
Tel: 732-4988
Email: IgorBucarelly@hotmail.com

Manuel Heredía, Director Watershed Unit
Tel: 547-3888 ext. 2214
Fax: 547-2185
Email: suelo.agua@codetel.net.do

Felícita Heredia, Director of Conservation and Management, Sub-Secretary of Coastal and Marine Resources
Tel: 732-4988
Fax: 547-3057
Email: felicitaheredial@yahoo.com

Ramona Nolasco, Director of Fisheries, Sub-Secretary of Coastal and Marine Resources
Tel: 732-4988
Fax: 547-3057
Email: ramonarosan@hotmail.com

Matilde Mota, Office of Research, Sub-Secretary of Protected Areas and Biodiversity
Tel: Tel: 809-472-4104/4204/3717/3911
Fax: 809-472-4012
E-mail: dnp@codetel.net.do

Mariana Perez, Director of DIARENA (Dirección de Información Ambiental y de Recursos Naturales)
Tel: 472-4204

Consorcio Ambiental Dominicano/Dominican Environmental Consorsium

Rosa Lamelas Lockward, Director
Tel: 532-5857
Fax: 535-0689
Email: cad@codetel.net.do

CEBSE (Centro para la Conservación y Ecodesarollo de la Bahía de Samaná y su Entorno/Center for the Conservation and Eco-Development of Samana Bay and its Surroundings)

Patricia Lamelas, Director
Tel: 852-6619; 538-2042
Email: cebse@intelnet.codetel.net.do
lamelasp@yahoo.es

David Buglass
Tel: 538-2042
Email: mail@davidbuglass.de
cebse@intelnet.codetel.net.do

IRG

Bill Kaschak, Chief of Party
Tel: 542-6888 ext. 2712

Fax: 549-5706
Email: bkaschak@unphu.edu.do

Josefina Espaillat, Environmental Investment Fund Coordinator
Tel: 542-6888 ext. 2709
Fax: 549-5706
Email: jespaillat@unphu.edu.do

CEDEP

Giulio Marín, Director
Tel: 538-3162
Cell: 1- 805-6195
Email: giuliomarin@hotmail.com

Jesús Galán, Biologist
Tel: 538-3162

Appendix 1

WATER BUDGET OF THE YUNA RIVER WATERSHED

CONTENTS

I.- Introduction

This hydrologic evaluation of the Yuna watershed has been contracted by The Nature Conservancy country program and is part of the activities of the project "impacts of altered freshwater flows to estuaries: development and application of methods to characterize current and future conditions and formulate action strategies." The evaluation was aimed to determine the climatic and hydrologic conditions of the lowermost part of the watershed, since these conditions could affect the fauna and flora of the estuary of Samana Bay at the mouth of the Yuna. Within the framework of the hydrologic evaluation, the following activities were undertaken:[9]

1. Search, gathering and analysis of the existing hydrologic and climatic data and information for Yuna watershed as well as the watershed characterization base don the existing information available at the various entities that interact in the watershed.
2. Trace the hydrologic boundaries of the watershed, including identification of the most important tributaries, especially the ones where water is diverted for aqueducts and irrigation systems.
3. Take measurements in the lower watershed to validate some of the gathered information and to provide information on some of the parameters where data was not found during the compilation of data and information.
4. Prepare a map highlighting the locations of the net of hydro-meteorological stations in the watershed.

II.- Previous studies

The most important studies, projects and programs that have been conducted in Yuna watershed have been lead by the Instituto Nacional de Recursos Hidraulicos (INDRHI). Among those can be distinguished the following:

- National Plan for Research, utilization and control of underground water
- Programs for watershed management
- Project AGLIPO I
- Project AGLIPO II

- National hydro-geological study, Phase II (under current execution)
- Irrigation districts

III.- Objective

The main objective of this assessment was to determine the hydro-climatic parameters necessary to develop a water budget in the estuary that allow us to quantify the water inflows and outflows.

IV.- Hydrologic and climatic aspects of the Yuna watershed

IV.1- General description of the watershed

The Yuna River, one of the largest of the Hispaniola, has a watershed area of 5498 km^2. It is located in the central part of the Dominican territory and extends to the Cibao eastern plain; the river head start its flow in the east part of Cerro Montoso and in the south of Firme Colorado, at 1150 meters of elevation; the watershed elevation ranged from 0 to 2500 msnm. Yuna River has a channel length of 138.6 km and its limits are the following:

- Limits to the North with the watershed of the rivers Boba and Nagua
- Limits to the South with Ozama and Haina watersheds
- Limits to the east with Bahía de Samana and Los Haitises mountain range
- Limits to the West with the watersheds of the rivers Yaque del Norte and Nizao.

From its source, the river flows to the Southwest and later it turns to the West. After converging with Arroyo Blanco, in the community of El Torito, the river turns to the Northwest. In its trajectory, Yuna River receives the inflows of various effluents and after converging to Blanco river Yuna turns to the Northeast crossing to the North of Bonao City. After converging with Masipedro River in Bonao, Yuna shift to the East to find Maimon River. After Maimon, Yuna shift its direction again towards the North, sometimes changing directions to the Northeast and keeping that way until converge with Camu River where the Yuna continues its direction to the East until crossing the plain of the lower Yuna.

From its convergence with the Camu River, Yuna journey continues near to Los Haitises mountain range and it receive the inflows of Cevicos, Payabo and Guaraguao rivers; maintains its direction to the East until reaching Samana Bay where it flows, but before reaching the river

[9] It is important to indicate that the time allocated for the preparation of the watershed hydrological assessment was too short, and that is why we were not able to get some field data, but those were estimated.

mouth, the main channel is divided in two. This division occurs in the community of Agua Santa de Yuna, located seven kilometers to the West of Saman Bay. This division took place at the end of the decade of the 50's when was built a dike to derive the waters of the river and feed a small irrigation channel that, in turn, irrigated the fields located in Barracote area. After the pass of several atmospheric phenomena the channel was widened due to the instability of the soil in its borders. The increase in its channel was so significant it caused the Yuna to join the Barracote River. The Yuna inflows to the Samana Bay by this drainage has a greater channel than the one by its natural drainage in the proximity of Sanchez.

In measurements conducted in both drainages during the 17th of August 2004 we gathered a flow of 22.197 m^3/s in the old drainage of Yuna and 144.826 m^3/s in Barracote. To conduct these measurements a boat and out of board engine were used, because of the depth of the riverbed. During the field exercise it was possible to verify that old Yuna drainage carried only a sixth parts of the flow that inflow into Samana Bay. We should clarify that at the moment of the field exercise the weather conditions were not the normal ones since strong rainfall have taken place in the low part of the watershed and the readings of river channel measurements were higher than the normal levels of dryness.

In the estuary, Yuna River receives inflows from several springs through Barracote River, as well as from streams and lagoons from Los Haitises hills. Some of these tributaries are Laguna Cristal, Lagunita Cristal, Laguna Las Cuevas, and the streams Paraguay and Barraquitos. All these inflows converge to the right margin of Yuna River.

The main tributaries in the medium-high part of the Yuna watershed are: Blanco River, which starts to flow in Parque Nacional Valle Nuevo; in the North part of Alto Bandera hills, Rio Blanco has Tireo River as a tributary. At Tireo watershed there is almost a total lack of vegetal cover and in consequence, is the watershed with largest sediment production. Also Masipedro River belongs to the Yuna watershed and starts its flows in the protected area of Las Neblinas. In its medium-low part receives the inflows of Yuboa and Maimón rivers, which start their flows in the north part of Cuesta La Vaca and Loma de los Chicharrones respectively. In these sub-watersheds a large part of the countryside is dedicated to livestock but there are also some wood production ranches. In the low part of the watershed, Yuna receives the inflows of its principal tributary, Camu River, which start flowing in Loma de Casabito, within the borders of the Ebano Verde Scientific Reserve. This joint is located near to Hostos town. The vegetal cover of this watershed around Camu and Jima rivers and in its medium-high part is in good conditions with plantations of Ebany, Pino and other trees with big leaves. In the low part correspondent to Valle de la Vega Real there exists large rice crops.

IV.2. - Weather of the Watershed.

The watershed's weather is very variable. At Rio Blanco head very low temperatures are registered due to its closeness to Alto Bandera mountain. In its high part, according to data collected at Los Botados climatologic station, temperature ranges between 12-23°C (minimum and maximum, respectively) but we can say that, in general, the temperatures at the watershed oscillate between 12-31°.

In terms of rainfall, Yuna watershed is one of the most humid parts of the country and Yuna river is considered the one that carries the greatest water volume of the East part of Hispaniola, having areas of rainfall higher than 3000 mm/year, but that can shift to 1000 mm/year. In the tributaries that start flowing in the South side of the Septentrional mountain chain, weather is different because the temperatures are higher and there is less rainfall, causing the flow in the channels to be smaller.

In Yuna watershed there are six dams already functioning and another one under construction. These dams are: Blanco dam, Arroyón dam, Tireito dam, Yuboa dam, Hatillo dam, Rincón dam and Guaygüí dam, which is under construction process.Furthermore, there are a series of dikes that divert water to aqueducts and irrigation channels for agriculture fields.

IV.3.- Landscape

Yuna watershed has a good vegetation cover, especially in the sub-watersheds of Maimón, Arroyo Blanco, Masipedro, Jima and Camú. In this area, plantations of Pinus, long leave tress, manaclares, and coffee and cacao crops can be observed, but in the case of Blanco River the situation is different, due to influence of Tireo River which watershed is completely eroded and with intense agriculture activities.

In the lower Yuna valley, the main activity is agriculture, especifically rice farming, that occupy 95% of the area suitable for farming. For rice farming a large quantity of water is utilized from Yuna River and its tributaries, plus the inflows that come from Los Haitises area though lagoons and springs. The portion that forms part of the estuary has the largest mangrove reserve of the

Hispaniola occupying an area of 70.22 km^2 disseminated across the Yuna mouth and to the whole wide of the Bay, extending more than five kilometers through the wetlands located in the proximities of Ciénaga de Barracote, Laguna Cristal, Guayabo and Los Haitises.

IV.4.- Level

The level of the watershed varies since its main water heads are located in the Central Mountain chain reaching elevations higher than 2500 msnm, near to Alto Bandera mountain. In the Septentrional chain, the elevations are not so high, not exceeding 1000 msnm. The watershed of Payabo River and the lagoons are within the mountain system of Los Haitíses which elevations do not exceed 550 msnm.

V.- Water budget in the low watershed

V.1.- Inflows to the river

V.1.1.- Water flow in the Yuna river and its tributaries

Yuna River has a length of 138.6 km in a watershed perimeter of 420 km. In the sector of Agua Santa de Yuna, the river divides in two: one goes to the northwest to the water mouth, near to Sánchez town and the other one goes to the northeast towards Ciénaga de Barracote where it is named Yuna Barracote, then it continues its flows to its water mouth in Samana Bay close to Los Haitises. The most important tributaries are the following:

- **Arroyo Blanco;** in which the construction of a dam for generation of electricity is being thought.
- **Tireito;** where Tireito and Arroyón dams are located
- **Río Blanco**; where Blanco dam is located.
- **Arroyo Avispa;** in which the work for the aqueduct of Bonao is located and at the lowermost part of the downstream is located the channel of Yuna Caracol.
- **Río Masipedro;** in which the dose of the channel Los Arroces is located
- **Río Yuboa;** where Yuboa (Aniana Vargas) dam and the dose of Yuboa channel are located.
- **Río Maimón;** at the lowermost part of the downstream confluence it is located Hatillo dam, which is the most important dam in terms of storage capacity for great water volumes and flood controls. Downstream of the dam it is located the dose of the channel Yuna Los Corozos.
- **Río Maguaca and Río Chacuey**; where feasibility studies for dams with multiple purposes have been initiated.

- **Río Camu**; in which Rincón dam is located as well as the dose of the channel Camú-Jamo and the channel system for Jima East Margin and West Margin.
- **Río Payabo**; the dose of the channel Payabo is located here, downstream of the confluence of it with Yuna where a diverter dike of the channels of Aglipo I (that direct its waters to the neighboring watershed of Nagua river) and Aglipo II that direct its waters to Aguacate Guayabo zone.
- Other tributaries that flow in Yuna Barracote are Arroyo Barraquito, Arroyo Paraguay, Arroyo Cristal, lagunita Cristal and Las cuevas lagoon.

In the watershed of the Yuna and its tributaries there are 20 hydrometric stations that belong to INDRHI. We have selected six stations for this study (see hydrographic map):

- **Los Quemados station**; is located in Los Quemados section, five kilometers far from the west of Bonao City. At Los Quemados the annual mean flow was 15.83 m^3/s. For the period between 1962 and 1979. The maximum flow observed at the station was 56.52 m^3/s in September 1976 and the minimum was 2.42 m^3/s in April 1965 (see table No. 01).
- **Maimón station**; it is located $1^{1/2}$ km away of Maimón town; in this station the annual mean flow was 5.15 m^3/s, for the period between year 1968 and 2000. The maximum flow observed in the station was 40.03 m^3/s in September 1988 while the minimum was 0.12 m^3/s in September 1991 (see table No. 05).
- **La Bija station**; is located 4 km away of the Pimentel town following the curse of the road from Las Matas de Cotuí to Pimentel. At La Bija station, the annual average water volume was 36.23 m^3/s. for the period between 1968 and 2002. The maximum flow observed in this station was 145.88 m^3/s in November 1996 and the minimum was 2.79 m^3/s during July 1975 (see table No. 06).
- **Villa Riva station**; this station is located in Villa Riva, downstream of the bridge over the road that goes to La Ceiba de los Pájaros; in this station the average annual flow was 89.38 m^3/s for the period between 1956-1992. The maximum flow observed at the station was 402.52 m^3/s during May 1979 and the minimum was 6.08 m^3/s during March 1977 (see table No. 02).
- **Payabo station;** this station is located in the Hiatuses area, near to Rincon Claro town, 4km away of the confluence of Ara river. At this station the average annual flow was 5.79 m^3/s for the period between 1971-1995. The maximum flow observed at the station was 22.68 m^3/s during May 1983 and the minimum was 0.47 m^3/s in March 1977 (see table No. 03).

- **El Limón station**; this station is the most downstream control point of Yuna river prior diverting its flow in Agua Santa de Yuna. It is located $1^{1/2}$ km downstream of the bridge of La Reforma. The average annual flow at this station was 102.39 m^3/s, for the period between 1968-2003. The maximum flow observed at the station was 374.68 m^3/s in May 1981 and the minimum was 10.87 m^3/s during April 1975 (see table No. 04).

Methods

The water flow data in each of the stations considered for this study were gathered through direct measurements with a pinwheel and monthly frequency was obtained through reading of limnimetric scales two times per day during dry season and more frequently during large floods. All the stations were doted with automatic measurement equipment but after the pass of hurricane George they were cast away by the strong currents. Up to this date these automatic equipment have no yet been reinstalled. The data from the stations are calibrated using calibration curves of Gumbel, extrapolating data to obtain the maximum flow during the floods that can not be measured with the regular gauging equipment.

V1.2.- Local runoff of surface water to the river from the watershed area located downstream of the lowermost river flow gauging station

Local runoff was determined at El Limon gauging station since this is the last control point where the inflows of the various tributaries that compose the watershed are collected. At El Limon, the watershed area is approximately 5115 km^2, and the area from that point to the river mouth including the estuary is 383 km^2. At this control point we were able to determine that the middle flow was 102.39 m^3/s and that the lowermost flow was registered during the period between January-April and August-September (Fig. No. 05).

V.1.3.- Groundwater inflow to river downstream of the lowermost river flow gauging station

Neither on the literature review of previous studies nor the direct observations conducted in the area were we able to identify significant groundwater flows. So, for the purpose of this study we were not able to quantify the groundwater inflows.

V.1.4.-Return flows to the river from agricultural, municipal or industrial areas that enter the river downstream of the lowermost river flow gauging station

At Arenoso town there are diverting dikes for the channels of the projects Aglipo I and II, but only the channel of Aglipo II has an incidence in Yuan watershed. It has a capacity for conducting and distributing10.5 m^3/s and it is utilized to irrigate the fields of Aguacate – Guayabo area, located in the left margin of Yuna River. Approximately 500 meters downstream of the dose of channel Aguacate – Guayabo a flow of 2.7 m^3/s, is diverted and decanted to the watershed of Nagua river for the irrigation of rice fields in that area. In this channel remains a flow of 7.8 m^3/s that is utilized for irrigation of 7353 hectares. According to the calculations, the return rate from the rice crops varies from 20 to 25 % of the water volume used, taking this into account, the return flow will be 1.56 m^3/s.

At Limón de Yuna zone there is a lack of a channel net where the irrigation area of the right margin of Yuna River is located and the inflows to the irrigation area is taken from different existing sources (what have been already mentioned) including pumping of the main drainage of Yuna River. At this point the return flow could not be quantified so we proceeded to make the calculations using irrigation estimates for rice cultivation of 1 liter/s/hectare and considering that the area under cultivation was 7,500 hectares. Based on that we have estimated a flow of 7.5 m^3/s, were we can deduce that the return flow was 1.5 m^3/s. in each margin. In consequence, we can estimate that the return flow for both margins was 3.06 m^3/s.

V.2. – Outflows of water from the river

V.2.1.- Human diversions of water from the river downstream of the lowermost river flow gauging station(s), including both surface and groundwater diversions:

Downstream of El Limón station does not exist any type of decanting or diversion of the river flow to another watershed or other areas. Furthermore, it does not exist any type of exploitation of the ground water.

V.2.2.- Evapotranspiration of water in the river downstream of the lowermost river flow gauging station

Evapotranspiration implies the presence of evaporation of water and plants transpiration. To obtain an idea of the evapotranspiration in areas close to the gauging station of El Limón, we proceeded to calculate these parameters based on climatologic data gathered at Barraquito station (table No. 39). The results obtained through the calculations give a potential evapotranspiration of 1345.3 mm/year and 1445.5 mm/year for the real or true evapotranspiration.

VI.- Water Budget in the Estuary

VI.1.- Direct precipitation of water on the estuary

The direct rainfall in the estuary was calculated taking into consideration an approximate area of 70.22 km^2 for the estuary and, based on the registered rainfall at the Barraquito climatic station, which presented an average annual rainfall of 2000 mm. Considering that the rainfall behavior of this area is similar to the surrounding areas due to the closeness between the estuary and the station, we did the following relationship: 1mm = 1 lit/m^2 = 10 m^3/Ha. With this relationship the rainfall was determined. As stated before, the estuary area corresponds to 70.22 km^2, equivalent to 7022 Ha. and average annual rainfall is 2000 mm/year, equivalent to 20000 m^3/Ha/year. From this, we estimated that the total annual direct rainfall into the estuary is around 140,440,000 m^3.

VI.2.- Net inflow of water to the estuary

These exits correspond to flow values obtained downstream of the lowermost river flow gauging station. The values are obtained from El Limon plus the runoff inflows from the river after the control station. The control station is the one located at El Limon which has an average annual flow of 102.39 m^3/s. The estimated flow as effect of returned water from agriculture practices was 3.06 m^3/s. Therefore, the estimated net inflow of water to the estuary, from the river is 105.45 m^3/s.

VI.3.- Groundwater discharge directly entering the estuary

It was not possible to obtain the available information regarding groundwater discharge especially due to the short time to undertake this study.

VI.4.- Watershed runoff directly into the estuary

As indicated before, the total area of the watershed is 5498 km^2 and the area up to the control station is, approximately 5115 km^2. We estimated the area of the estuary in approximately 383 km^2 equivalent to 7 % of the total area of the watershed. In view that the water runoff in the watershed until the control gauging station (El Limon) was estimated in 102.39 m^3/s; it was deduced that direct runoff from the watershed to the estuary is related to the runoff from El Limon until the estuary plus the inflows from water that return after been used in agricultural activities. The value gathered based in these relationships was 112.83 m^3/s.

VI.5.- Evapotranspiration from the estuary

To determine the evapotranspiration in Yuna watershed we proceeded to analyze the data obtained at the most representative climatologic stations using the Thornthwaite method. The values gathered for each station were the following:

Table No.39: Evapotranspiration as calculated at the various stations of the watershed

CLIMATOLOGIC STATION	POTENTIAL EVAPOTRANSPIRATION (mm/year)	REAL EVAPOTRANSPIRATION (mm/year)
LA ANGELINA	1497.2	1479.1
JUMA	1438.4	1489.9
EL NOVILLO	958.8	987.4
LOS BOTADOS	899.8	874.9
BARRAQUITO	1345.3	1445.5

We have explained before that Barraquito station is the one that best fit within the climatologic conditions of the estuary and in consequence the values given for Barraquito stations can be also considered for the estuary.

VII.- Conclusions

Analyzing the values derived from the assessment of the inflows and outflows of water from Yuna watershed at the control station, we found that the results do not correspond to a real equilibrium. The addition of the flows at the stations located high stream of the control station have a value of 152,38 m^3/s., but there exist several outflows from these stations which flows through channels that could not be quantified due to the short time available for the study. The difference between this value and the results of the inflows at the control station corresponds to outflows and other not quantified water lost.

Regarding to the estuary balance it is noted that the water inflows to the same, mainly due to direct rainfall, inflows from the river and direct watershed runoff; bring to the estuary a water budget of 222.78 m^3/s, while the outflow obtained based on the calculation of evapotranspiration, provided a value of 218.20 m^3/s. Even though the results obtained during the evaluations cited above are not very different, we conclude that the analyzed data should be further review and validate.

VIII.- Recommendations

In view of the conclusions in regards to the review and validation of the observed data, we recommend to conduct the following activities:

- Validate the climatologic parameters at the watershed and the estuary in order to obtain a better balance of the water inflows and outflows. In other words, a balance where the inflows and outflows are in equilibrium.
- To program campaigns for flow measurements in the field, downstream waters of the control station so that it will be possible to validate the data “in situ”.
- Programming campaigns of hydrogeological research in order to identify groundwater flows.
- Verify the available cartography in order to provide more precision on the areas of the watershed, of the estuary and land use.