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Project Yuna River Basin: Phase II

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PROJECT YUNA RIVER BASIN
PHASE II

CONTENTS

I. Introduction

This hydrological evaluation of the high and medium basin of the Yuna River was financed by The Nature Conservancy as part of a series of activities named “Yuna Basin Project”. The purpose of the study is assessing the climatic and hydrological conditions of the high and medium part of the basin that influence the flora and fauna of the estuary located in the east of Samaná bay and to complete the study on Yuna River started in 2004.

As part of this hydrological evaluation the following activities were carried out:

- Summary and analysis of the existent climatic and hydrological information of the basin in general, and characterization of the elements that interact in the basin.
- Delimitation of the basin and the high and medium hydrological web, including the characterization and valuation of the most important tributaries, especially those from which aqueducts and watering systems take water.
- Map with the net of hydro-meteorological stations located at the high and medium levels of the basin.

II. Antecedents

The most important projects and programs that have been carried out so far in this basin have been directed by the INDRHI (Dominican Institute for Hydrological Resources) and among them they can be distinguished the following ones:

- National plan of Investigation, Use and Control of Underground Waters
- Programs of basin management
- Project AGLIPO I
- Project AGLIPO II
- National Hydrological Study Phase II
- Districts of Watering
- Project Yuna
- Hydroelectrical damps in the Dominican Republic

III. - Objective

To obtained the climatic, hydrological and hydro-geological information necessary to complete de first phase of the Yuna River Project.

IV. - Hydrological and climatic aspects of the high and medium basin

IV.1 - General description of the basin

The Yuna river, one of the main watersheds of the Hispaniola island, has a total area of 5498 km2, it is located in the central part of the Dominican Republic and extends toward the plain of the oriental Cibao; its headwaters are located to the west part of Cerro Montoso and to the south of Firme Colorado (1150 meters above sea level). This watershed ranks from 0 to 2500 meters above sea level with a length of 138.6 kilometers. The limits of the basin are:

- To the north it limits with the Boba and Nagua rivers
- To the south with the basin of the Ozama and Haina Rivers
- To the east with the Bay of Samaná and Los Haitises mountain chain
- To the west with the basins of Yaque del Norte and Nizao rivers.

From its beginnings the Yuna river begins a journey toward the Southwest to rotate to the west, after converging with the Blanco stream and at the community of El Torito it turns toward the northwest.
In this itinerary receives the contributions of different flowing and after converging with the Blanco river turns toward the northeast crossing to the north of the city of Bonao, and after joining with the Masipedro river it changes its orientation toward the east until converging with the Maimón river, then it changes its course again, toward the north, varying in occasions toward the northeast until converging with the Camú river, beginning a journey toward the east until crossing the plain of Low Yuna.

From the point of confluence with the Camú river next to the mountain of Los Haitises, the Yuna River receives the contributions of the rivers Cevicos, Payabo and Guaraguao; maintaining this orientation toward the east, until arriving to the Samaná bay where it ends, but before arriving to the outlet, the main bed is divided into two and this way it forms the estuary. Therefore, this main bed has two permanent water exits to the bay and this division occurs in the town of Agua Santa del Yuna, at 7 kilometers to the west of the Samaná Bay. The history of this division goes back to the late 50s when a dike was built to feed a small watering channel for the lands located in the area of Barracote; after some atmospheric phenomenon, the channel was enlarging its bed up to a point that the amplification of the bed was so significant that caused its union with the Barracote river. This exit to the Bay throughout this new bed has a bigger flow than its natural exit next to the town of Sánchez.

Measurements taken in both beds on August 17th 2004 for the first report of this work, the flows of both beds were obtained. For the bed of the old Yuna we had a flow of 22.197 m^3/s and for the bed of Barracote a flow of 144.826 m^3/s. These measurements were carried out from a motor boat, because of the depths of these beds, and it could be proven that the old or natural bed of the Yuna river has only about a 60% of the flow that arrives to the Samaná Bay. It is important to notice that on this date the climatic conditions in the area were not normal since strong rains had taken place in the smaller watersheds of the low part so the flow was above the normal levels.

In what concerns to this work (second part) a focus of the general aspects of the high and medium part of the basin will be presented, emphasizing in Camú River contributions.

The main tributaries to the medium-high basin of the Yuna river are: Blanco River which rises at Valle Nuevo National Park, to the north of Alto Bandera, and has a tributary named the Tireo River which is the main source of sediments to the basin because its watershed is severely deforested and Río Masipedro that rises in the protected area of Las Neblinas. The tributaries of the medium-low basin are Yuboa and Maimón Rivers, which rise to the north of Cuesta La Vaca and to the north of the hill of Los Chicharrones respectively. These areas are partially used for cattle activities and wood production.

Medium and high areas of this basin are in good condition only in the watersheds of Camú and Jima rivers with plantations of ebony, pine and some Latifoliadas. In the low part called Valle de la Vega Real there are big plantations of rice.

IV.2. - Climate of the basin

The climate of this basin is very varied, since in the area where Blanco River rises very low temperatures are registered because of the proximity to the highlands of Alto Bandera (12ºC-23ºC taken at station of Los Botados). In general the temperatures of this basin vary from 12 to 31 ºC.

In regard to precipitation, this is one of the most humid basins of the country with precipitation levels up to 3000 mm/year, but with a range from 1000 mm/year in some areas. For the tributaries that rise in the south slope of Cordillera Septentrional, the situation of the climate is different since temperatures are higher and precipitation lower, causing that the flows of these rivers are smaller.

V. - Climatology and superficial hydrology in the high and medium basin

V.1. - Climatology

For the evaluation of the climate in the high and medium basin of Yuna River we used information coming from climate stations of the INDRHI and of the National Office of Meteorology. We have also used data from the project National Hydrogeological Study (phase II).

V.1.1. – Temperature analysis in the high and medium basin of Yuna River

As we explained before, data used come from the stations recorded by the mentioned institutions. For the high basin data correspond to the following stations:

- Los Botados. maximum temperature: 22.6ºC for June 1997; minimum temperature 17.8ºC for December 1999 (see Table 20). Figure 20 shows months where temperatures are lower correspond to December to February, while the months where the temperatures are higher correspond to June to September.
- El Novillo. maximum values of temperature 22.7ºC went for May 1995 minimum temperature 17.2ºC for December 1984 (Table13). Figure 13 shows lower temperature months (December-February) and higher temperature months (July to September).
- José Contreras. maximum temperature: 25.7ºC for September 1997; minimum temperature: 19.7ºC for January 2000 (Table 25). Figure 25 shows lower temperature months (December to February) and higher temperature months (July to September).

For the medium basin data correspond to the following stations:

- Juma. maximum values of temperature 27.2ºC for June 1994; minimum temperature 20.8ºC for February 1974 (Table 45). Figure 45 shows lower temperature months (December to February) and higher temperature months (July to September).

In the medium basin of Yuna River data correspond to the following stations:

- La Vega. maximum temperature: 34.0°C for a series from 1961 to 1996; minimum temperature: 18.4°C for January 1961-1996. Figure 31 shows lower temperature months (December to February) and higher temperature months (July to September).
- Moca. maximum temperature: 31.9ºC for September 1961 to the 1996; minimum temperature: 18.4ºC January of 1961-1996 (Table 27). Figure 27 shows lower temperature months (December to February) and higher temperature months (July to September).
- Salcedo. maximum temperature: 37.7ºC for September 1961 to 1996; minimum temperature: 18.4ºC for January 1961-1996 (Table 29). Figure 29 shows lower temperature months (December to February) and higher temperature months (July to September).
- San Francisco of Macorís. maximum temperature: 27.5ºC for August 1987; minimum temperature: 22.6ºC for January 1979 (Table 33). Figure 33 shows lower temperature months (December to February) and higher temperature months (July to September).
- La Angelina. maximum temperature: 30.7ºC for June 2003; minimum temperature: 22.4ºC for January 2000 (Table 41). Figure 41 shows lower temperature months (December to February) and higher temperature months (July to September).
- Cotuí. maximum temperature. 33.3ºC for September 1961 to 1996; minimum temperature: 18.5ºC for January 1961-1996 (Table 37). Figure 37 shows lower temperature months (December to February) and higher temperature months (July to September).
- Cevicos. maximum values: 32.1ºC for September 1961 to 1996; minimum temperature: 17.5ºC for January 1961-1996 (Table 50). Figure 50 shows lower temperature months (December to February) and higher temperature months (July to September).

V.1.2. - Precipitation analysis in the high and medium basin of Yuna River

As we explained before, data used come from the stations recorded by the mentioned institutions. For the high basin data correspond to the following stations:

- Los Botados. maximum values of precipitation 568.8mm went for November 1998; while the minimum values are 14.3mm for December (Table 17). Figure 17 shows that the months with lower precipitation are January-April and June-July, while the months with higher precipitation are May and August-December.
- Los Novillos. maximum values of precipitation 583.4mm for May 1983; while the minimum values are 13.1mm for June 1992 (Table 10). Figure 10 shows that the months with lower precipitation are February-April and July, while the months with higher precipitations are May and August-January.
- José Contreras. Maximum values of precipitation 540.0mm for November 2003; while the minimum values are 8.0mm for March 2003 (Table 23). Figure 23 shows that the months with lower precipitation

are February and March besides June-August, while the months with higher precipitation are April and May as well as September and January.

- La Ceiba. Maximum values of precipitations 1060.3mm for May 1993; while the minimum values are 3.0mm for February 2000 (Table 22). Figure 22 shows that the months with lower precipitations are February-March and June, while the months with higher precipitations are April-May and July November.

For the medium basin data correspond to the following stations:

- Juma. maximum values of precipitation 585.5mm for May 1983; while the minimum values are 9.6mm for March 1977 (Table 20). Figure 20 shows that the months with lower precipitations are January-March and June-August, while the months with higher precipitation are April-May and September-December.
- La Vega. maximum values of precipitation 192.5mm for May 1961 to 1996; while the minimum values are 74.8mm 1961-1996 (Table 30). Figure 30 shows that the months with lower precipitations are January-March and June -September, while the months with higher precipitation are April-May and October-December.
- Moca. maximum values of precipitation 160.7mm for May 1961 to 1996; while the minimum values are 63.9mm for February 1961-1996 (Table 26). Figure 26 shows that the months with lower precipitation are January-March and June-August, while the months with higher precipitation are May and September-December.
- Salcedo. maximum values of precipitation 227.0mm for August 1961to 1996; while the minimum values are 69.1mm for February 1961-1996 (Table 28). Figure shows that the months with lower precipitation are January-March and June -July, while the months with higher precipitation are April-May and August-November.
- San Francisco de Macorís. maximum values of precipitation 400.3mm for August 1979; while the minimum values are 3.3mm for February 1987 (Table 32). Figure 32 shows that the months with lower precipitation are January-March and June, while the months with higher precipitation are April-May and August-November.
- La Angelina. maximum values of precipitation 618.7mm for May 1987; while the minimum values are 3.3mm for March of the year 1992 (Table 38). Figure 38 shows that months with lower precipitation are January-March, while months with higher precipitation are April –mayo and September-November.
- Cotuí. Maximum values of precipitation 228.0mm for May 1961to 1996; while the minimum values are 89.6mm for January 1961-1996 (Table 36). Figure 36 shows that months with lower precipitation are but January-March, while months with higher precipitation are April-May and August-November.
- Cevicos. maximum values of precipitation 285.4mm for August of a series that she/he goes from 1961al 1996; while the minimum values are 81.2mm for February 1961-1996 (Table 49). Figure 49 shows that the month with lower precipitation are January-March, while months with higher precipitation are April-November.

- Naranja Dulce. maximum values of precipitation 318.0mm for May 1993; while the minimum values are 50.5mm for July 1994 (Table 51). Figure 51 shows that the months with lower precipitation are December-February, while months with higher precipitation March-June and September-October.
- Los Ranchitos. maximum values of precipitation 317.0mm for November 1968; while the minimum values are 6.1mm for February 1969 (Table 35). Figure 35 shows that the months with lower precipitation are January-March, June-July, while months with higher precipitation are April-May, August and November-December.
- Licey Naranjal. maximum values of precipitation 499.3mm for May 1982; while the minimum values are 2.2mm for February 1987 (Table 34). Figure 34 shows that the months with lower precipitation are January-March and June-August, while months with higher precipitation are April-May and September-November.
- Piedra Blanca. maximum values of precipitation 562.9mm went for May 1987; while the minimum values are 6.9mm for March 2000 (Table 48). Figure 48 shows that the months with lower precipitation are December-March, while months with higher precipitation April-November.

V.1.3. – Evaporation analysis in the high and medium basin of Yuna River

As we explained before, data used come from the stations recorded by the mentioned institutions. For the high basin data correspond to the following stations:

- Los Botados. maximum values of evaporation 193.2mm for June 1985; while the minimum values are 64.4mm for February 1997 (Table 18). Figure 18 shows that the months with lower evaporation are November-February, while the months with higher evaporation are March-October.
- Los Novillos. maximum values of evaporation 208.9mm for October 1992; while the minimum values are 88.0mm for November 1984 (Table 11). Figure 11 shows that the months with lower evaporation are January-April and November, while the months with higher evaporation are May-October and December.
- José Contreras. maximum values of evaporation 198.4mm for March 2003; while the minimum values are 72.4mm for October 2003 (Table 24). Figure 24 shows that the months with lower evaporation are December-February, while the months with higher evaporation are March-November.

For the medium basin data correspond to the following stations:

- Juma. maximum values of evaporation 236.3mm for June 1988; while the minimum values are 33.4mm for February 1974 (Table 44). Figure 44 shows that the months with lower evaporation are November-February, while the months with higher evaporation are March-October.
- La Angelina. maximum values of evaporation 237.4mm for July 1995; while the minimum values are 87.4mm for December 1999 (Table 39) Figure 39 shows that the months with lower evaporation are November-February, while the months with higher evaporation are March-October.

V.1.4. – Relative humidity analysis in the high and medium basin of Yuna River

As we explained before, data used come from the stations recorded by the mentioned institutions. For the high basin data correspond to the following stations:

- Los Botados. maximum values of relative humidity were 89.2% for June 2003; while the minimum values were 56.2% forAugust 1992 (Table 21). Figure 21 shows that the months with lower relative humidity are January-April, while the months with higher relative humidity are May-December.
- Los Novillos. maximum values of relative humidity were 96.9% for October 1995; while the minimum values are f 74.6% for August 1984 (Table 14). Figure 14 shows that the months with lower relative humidity are February and July-November, while the months with higher relative humidity are December-January and March-June.

For the medium basin data correspond to the following stations:

- Juma. maximum values of relative humidity were 96.2% for August 1974; while the minimum values are 70.7% for April 1984 (Table 47). Figure 47 shows that months with lower relative humidity are March-April and June-July, while the months with higher relative humidity are January-February, May and August-November.
- La Angelina. maximum values of relative humidity were 94.1% for November 1979; while the minimum values are 70.1% for March 1987 (Table 28). Figure 28 shows that the months with lower relative humidity are March-June, while the months with higher relative humidity are January-February and July-December.

V.1.5. - Potential evapo-transpiration analysis in the high and medium basin of Yuna River

The potential evapo-transpiration (PET) for this work was taken from calculations carried out in the "National Hydro-Geological Study" (Phase II) and in the "Yuna River Study" (first part), in which the method of Hargreaves was used. Compared to other methods, this is considered appropriate for tropical areas. With this method the value of the monthly PET is obtained from the monthly average temperature, the monthly average of daily maximum temperatures, and the solar radiation.

The stations selected for these calculations in the basin correspond to those located in the following places:

- La Angelina, which is located in the medium low basin of Yuna River with an average value of 1497.2 mm/year.
- Juma, which is located in the medium high basin of Yuna River with an average value of 1438.4 mm/year.
- Los Novillos, which is located in the high basin of Yuna River with an average value of 958.8 mm/year.

V.2. - Superficial hydrology

V.2.1 - Superficial affluents of Yuna River in the high and medium basin

The Yuna River has a longitude of 138.6 kilometers, in a basin perimeter of 420 kilometers. In the Agua Santa del Yuna, the river is divided into two beds; one following the northwest orientation toward the outlet, next to the town of Sánchez and the other taking the northeast orientation toward the marsh of Barracote with the name of Yuna-Barracote and then to the outlet in the Samaná Bay next to Los Haitises.
The most important tributaries in high and medium basin are the following ones:

Blanco Stream. This is the main tributary of the Yuna River; It rises at the east of hill Cumunuco (1700 meters above sea level). It begins their journey toward the east and it maintains it until converging with the Yuna River in the town El Torito.

Tireito River. It rises in the hill Monteada Nueva (1800 meters above sea level). It begins its journey toward the northeast and in the town of El Candongo rotates toward the north until arriving to the place La Guázara, where it makes a turn toward the east until converging with the Yuna River. Its main tributaries are the stream Arroyón and the stream Toro Flaco.

Blanco River. It rises in Sabana Sin Provecho, to the east of the mountain Alto Bandera (2300 meters above sea level). It begins its journey to the northeast, and then turns toward the north, maintaining this orientation until converging with the Tireo river Tin the section El Rodeo, where it makes a turn to the east and that maintains until converging with the Yuna in the section Boca de Blanco. Its main tributaries are: Tireo River and the stream Sonador.

Arroyo Avispa. It rises to the east of the hill El Torito (1000 meters above sea level). It begins its northwest journey until the section Los Pozos Blancos, where it rotates to the north and then in hill of El Medio it rotates to the northwest until converging with the Yuna.

Masipedro River. It rises between the hills Masipedro and La Calentura (1700 meters above sea level). It begins a northeast journey which maintains until converging with Arroyo Bonito stream where makes a north turn but then it recaptures the orientation until converging with the Yuna river. Its main tributary is Arroyo Bonito stream.

Yuboa River; It rises in the northeast of the hill Cuesta de la Vaca (1212 meters above sea level). It begins a journey toward the east and then rotates to the northeast to the section Ensenada; when arriving to Rincón de Yuboa, it rotates toward the north and maintains that orientation until arriving to the Yuna. Its main tributary is the Juma river.

Maimón River. It rises in the hill Los Chicharrones in their northwest part (1307 meters above sea level). It begins a northwest journey in the section La Yautía, then turn toward the northeast, maintaining that orientation until converging with the river Los Plátanos, where it makes a turn to the north until the municipality of Piedra

Blanca, then turns again to the northeast until converging with the Yuna. Its main tributaries are Yautía stream, Los Plátanos River, Arroyo Vuelta stream and La Leonor river.

Camú River. It rises to the northeast of the Cazabito hill in the Scientific Reservation Ebano Verde, in the Central mountain range (1190 meters above sea level) It begins its journey with a northwest orientation, then it stops to make a turn to the north until arriving to the confluence with the Yamí river in the town Bayacanes, where it rotates toward the northeast and then to the east, maintaining this orientation until arriving at the town Las Cabuyas, in this point makes a turn toward the southeast, but before arriving at the town La Bija, this returns to the orientation until converging with the Yuna river next to the town called Platanal.

In its itinerary it receives the contributions of several tributaries among which we will mention the main ones, in the medium and high area Guaigüí, Guarey and Yamí rivers, and in the low area Licey, Cenoví, Jima and Jaya Rivers, except for the Jima River the other tributary are born in the south slope of the Northern mountain range.

This basin presents good plant cover in the bed of the Camú River until the confluence with Yamí where prevails the *Pinus occidentalis* and Green Ebony trees. In regard to the basin of Jima River in its high part and its tributary Jatubey and Jayaco we observed Pinus occidentalis, Latifoliados and some Green Ebony trees. The other tributaries are very impacted and just small spots of natural forest exist.

Jima River: It rises in the northeast of the hill of La Cabilma Clara (1000 meters above sea level). It begins its journey toward the northeast then rotates toward the east, then it recaptures the northeast orientation and then toward the north until arriving to the town Rincón and continues with this orientation until converging with the Camú river in the area of Zafabraya. In its itinerary receives the contributions of several tributaries from which the main ones are: Jatubey and Jayaco Rivers, which we already mentioned.

Licey River: It rises to the southeast of the hill named Licey Blanco, with in the Northern mountain range (740 meters above sea level), to some 9 kilometers of the town of Tamboril. It begins their journey toward the Southwest, in the town of Tamboril turns to the southeast and then rotate to the south, until making confluence with Arroyo Puñal stream, where then tour to east until it joins with the Moca river and then it recaptures the southeast orientation to the town Naranjal, where it rotates to the south until converging with the river Camú. In their itinerary receives the contributions of several tributaries from which we will mention the main ones: Canca River, Moca, Arroyo Puñal stream and Verde River. This is a basin very impacted since in the higher areas we observed cattle raising activities, in the medium level areas agricultural activities such as coffee, cocoa, citric and other, and in the lower areas small crops of short cycle.

Cenoví River: It rises in the hill Monte Llano in the southeast of the Northern mountain range, (680 meters above sea level). It begins its journey toward the south, stops and then rotates to the Southwest and in the town Ojo de Agua rotates again to the south; it maintains this orientation until the crossing of Bomb of Cenoví, where it rotates to the southeast until converging with the Camú River.

The condition of this basin is similar to that of the Licey River in regard to the impacts of the basin and its plant cover, with very intense agricultural use. The main tributaries of Cenoví River are: Arroyo Agua Fría stream and the Jayabo River.

Jaya River: It rises in the hill of Los Pomos de Jaya, to the west of the hill Loma Quita Espuela (400 meters above sea level). It begins its journey with a south orientation, stops to make a Southwest turn until crossing the city San Francisco de Macorís, after about 4 kilometers it recaptures the southeast south orientation until converging with the Camú river.

V.2.2. – Hydrometric Stations. Flows and Methodology.

V.2.2.1. - Flows and methodology

The flows in each one of these stations are obtained by means of direct measures using molinetes and with a monthly frequency, by reading limnimetric scales twice a day in the low water time and with a bigger frequency in the time of bigger flow. All these stations were equipped with automatic meters but after the pass of Hurricane George they were destroyed and so far they have not been reinstalled.
These stations are calibrated applying the systems of calibration of Gumbel, making extrapolation of data to obtain the maximum flows that can not be measured with the gauging equipment.

V.2.2.2. – Hydrometric Stations

In the high and medium basin of Yuna river and its tributaries exist several hydrometric stations owned by INDRHI. Nine of them have been selected for this study (see hydrographic map).

1. **Yuna-Los Quemados Station:** this station is located in the section Los Quemados about five kilometers approximately to the west of the city of Bonao; here we obtained an average flow of 15.83 m^3/s for the period 1962 to 1979. The maximum flow observed in the station was 56.52 ^{m3}/s in September 1976 and the minimum was 2.42 m^3/s in April 1965 (Table 06).
2. **Maimón-Maimón Station;** this station is located at 1 ½ kilometers approximately to the town of Maimón. In this station it was obtained an average flow of 5.15 m^3/s, for the period 1968 and 2000. The maximum flow observed in the station was 40.03 m^3/s in September 1988 and the minimum was of 0.12 m3/s in September 1991 (Table 07).
3. **Camú-the Bija Station**; this station is located at about 4 kilometers before arriving at the town of Pimentel trough the highway that goes from Las Matas to Cotuí. In this station an average flow of 36.23m^3/s, was obtained for the period 1968 to 2002. The maximum flow observed in the station was 145.88 m^3/s in November 1996 and the minimum was 2.79 m^3/s July 1975 (Table 08).
4. **Camú-Bayacanes Station**; this station is located at about 8 kilometers to the Southwest of the city of La Vega trough the highway that goes from La Vega to Jarabacoa. In this station an average flow of 4.26 m^3/s was obtained for 1960 to 1995. The maximum flow observed in the station was 31.07 m^3/s in May 1993 and the minimum was 0.74 m^3/s in June 1995 (Table 01).
5. **Licey-Naranjal Station**; this station is located at about 12 kilometers to the northwest of the city of La Vega through the highway that goes from La Vega to the city of Moca. In this station an average flow of 1.62 m^3/s was obtained for the period 1964 to 1987. The maximum flow observed in the station was 22.28 m^3/s in May 1981 and the minimum was 0.33 m^3/s in July 1977 (Table 02).

6. **Cenoví-Santa Ana Station**; this station is located at about 8 kilometers to the south of the city of San Francisco de Macorís through the highway that goes from San Francisco de Macorís to the community of Villa Tapia. In this station an average of 1.31 m^3/s was obtained for 1982 to 1995. The maximum flow observed in the station was 7.47 m^3/s in November 1985 and the minimum was 0.05 m^3/s in August 1991 (Table 03).
7. **Station Maguaca-La Cabilma**; this station is located at about 8 kilometers to the southeast of the city of Cotuí, trough the highway that goes from Cotuí to the community of Maimón. In this station an average flow of 1.33 m^3/s was obtained for 1982 to 1995. The maximum flow observed in the station was 11.84 m^3/s in May 1993 and the minimum was 0.12 m^3/seg in March 1994 (Table 04).
8. **Chacuey-Los Tres Pasos Station**; this station is located at about 7 kilometers to the east of the city of Cotuí, trough the highway that goes from Cotuí to the community of Cevicos. In this station an average flow of 1.53 m^3/s was obtained for 1984 to 1993. The maximum flow observed in the station was 12.11m^3/s in September 1988 and the minimum was 0.37 m^3/s in March 1992 (Table 05).
9. **Payabo-Abadesa Station**; this station is located at about 8 kilometers to the northeast of the community of Cevicos, trough the highway that from Cevicos to the community of Rincón Claro. In this station an average flow of 5.90 m^3/s was obtained for 1971 to 1995. The maximum flow observed in the station was 22.68 m^3/s in May 1983 and the minimum was 0.85 $^{m3}/s$ in February 1987 (Table 09).

V.2.3. – Hydroelectrical dams in the high and medium basin

The basin of the Yuna river has a series of hydroelectrical dams in operation, some of them in construction process, one about to begin and others that are in study process and search of financing.

These dams have been constructed especially with the purpose of supplying water for aqueducts, supplying water for agricultural production and for electric power generation. Few of them have the additional objective of controlling floods in vulnerable areas.

V.2.3.1.- Hydroelectrical Dams

Hatillo Dam. Located in the community of the same name, at about 6 kilometers to the southeast of municipality of Cotuí, Sánchez Ramírez. It has 1.8 kilometers in length and a capacity of water storage of 710 millions of m3. This is a multiple purpose dam, because besides the energy production, it supplies water for irrigation of the Cibao valley through the system Yuna-Los Corozos, reaching an area of irrigation of about 12570 Ha and in its lower area (El Limón del Yuna) it reaches 25385 Ha of land irrigated. This dam was built with the purpose of controlling the flow of this watershed to the area of Bajo Yuna, but because of the amount of water and the type of construction, when it reaches the maximum level of operation, the exceeding flow runs freely to the lower lands.

Río Blanco Dam. Located in the town of Blanco at about 22 kilometers to the southeast of the city of Bonao, Monseñor Nouel province, on Blanco River and below the confluence with Tireo River (624 meters above sea level). It has a water storage capacity of 725,000 m^3 and it was built for energy generation. It is the biggest of dam system of Blanco River which are connected through tunnels that converges at the town of Hoyo del Pino.

Tireíto Dam.; Located at the small town of Las Guázaras, in the watershed of Tireíto River, up to the confluence with Arroyón Stream, which is a direct tributary of Yuna River. As same as Blanco Dam it is for energy generation, and belongs to the dam system of Blanco River. The volume of the reservoir is 340,000 m^3.

Arroyón Dam. Located at the town of Las Guázaras next to the dam of Tireíto, up to the confluence with Tireíto River. It is also for energy generation and is the smallest of the complex of Blanco. The volume of the reservoir is 3,300 m^3.

Rincón Dam. Located at the watershed of Jima River, affluent of Camú, which is tributary of Yuna River, at about 1.5 kilometers from the town of Rincón in the province of La Vega. The water storage capacity is 75.5 millions of m^3. This is a multiple purpose dam because supplies water for the aqueduct of San Francisco de Macorís and Salcedo, for the water channels of Jima and for energy generation. With this channels 7,038 Ha are irrigated in the Vega Real valley.

Rincón de Yuboa Dam. This is also known as the hydroelectrical project Aniana Vargas, located in the small town Rincón de Yuboa, at about 20 kilometers to the southeast of Bonao city, in the province of Monseñor Nouel, in the watershed of Yuboa River. This is a small dam which feeds a channel of 1.32 kilometers long.

V.2.3.2. – Hydroelectrical dams in construction

Guaigüí Dam. Located at a distance of approximately 10 kilometers to the Southwest of the city of La Vega, in the high area of Camú River and down the confluence with Guaigüí River.
This dam is being designed for multiple purposes:

a) To mitigate damages from river floods to the city of La Vega
b) To supply water for the same city.
c) To supply 80% of the flow required to irrigate 600 Ha
d) Electric power generation

This prey will have a volume of storage of 47.5 millions of m^3, with a free draining system.

Pinalito Dam. It is in the initial phase of construction and is located in the small town of Pinalito, on the bed of Tireo River, down the confluence Pinalito stream. This dam is being constructed for electric power generation and since it is located up to Río Blanco dam, this water will be received in the reservoir of Río Blanco dam. This prey will store a volume of 18.6 millions of m^3.

V.2.3.3. – Dams under study

Piedra Gorda Dam. The design process is completed**.** The dam will be located at at about 2 kilometers up to the town of Los Quemados, less than 1 kilometer under the confluence with Blanco River. This dam will be used to give water for the aqueduct of the town of Bonao, it will produce electric power and the necessary water for irrigation of the lands of the valley of Bonao.
This dam will have a storage capacity of 65.0 millions of m with a free draining system and a discharge capacity of 3,240 m^3/s. It will also have a dike which will be the taking of a channel for irrigation of the valley of Bonao

and in its left margin a taking for the channel Yuna-Cañabón, which will allow enlarging the irrigation area of Rincón Dam with an additional flow of about 10.0 m^3/s.

Bonito (Hydroelectrical Project). The place for this project is called “Bonito” and is located in the high basin of the Yuna river, in the bed of the Masipedro river (893 meters above sea level). It will be a dam for electric power generation with a capacity of reservoir of 4.68 millions of m^3. The water will go to the reservoir of the Masipedro Dam. This project at the present time is on the preliminary study.

Masipedro Dam. To be constructed in the place called Masipedro located in the high basin of the Yuna River on the bed of the river of the same name (382.00 meters above sea level). It will be a dam for f electric power generation and will have a capacity of reservoir of 5.81 millions of ^{m3}. This project at the present time is on the preliminary study.

El Torito Piedra de los Veganos Dam. This will be a complex of small and medium dams that will be located in the high basin of Yuna river, in the town of Los Toritos**.** It will consist of two dams, one on the Yuna river before the confluence with Blanco River and the over Arroyo Blanco stream. The system will have two dikes to be built over Colorado stream and a fifth dam on the Yuna River, in the place called Piedra de los Veganos. This last one will be the highest dam with an useful volume of 149,000 m^3 at 493 meters above sea level.

Project Los Plátanos Dam. This dam will be built in the basin of high Yuna, in place called Los Plátanos, on the bed of the Maimón River (295 meters above sea level). This will be a dam for electric power generation.

Project Los Limones Dam. This dam will be located in the low basin of the Yuna river, on the bed of the Cenoví River, which is affluent of the Camú river which in turn is the main tributary of the Yuna river. This dam will be for storage of water for irrigation needs. This project at the present time is on the preliminary study.

V.2.3.4. - Impact of the dams on the river flows

Before being built the reservoirs, the big floods caused large loads of sediments toward the low basin. This problem has being diminished considerably after the construction of the dams. In other cases, the process of filling the reservoirs helped to control the river floods, but after reaching the reservoirs their maximum level of operation, the exceeding water continue to the bed of these rivers, since the reservoirs are built with free draining systems and therefore they will not control river floods. During the dry season when the reservoirs are in their minimum level of operation, these serve as controllers of floods and for water storage.

V.2.4. – Surface run-off toward the river from the high and medium basin

Surface run-off from basin should be determined in the stations of Bayacanes, Los Quemados, Naranjal, Santa Ana and Maimón, which are the control points for the flowing contributions of the different affluents that come from the high and medium basin. In these points the basin has an area of about 1215 $km^{2.}$ We measured an average flow of 30.17 m^3/s. The lowest flows are registered in January-April and August-November.

VI. - Flows of underground waters

VI.1. - Description of the hydrogeological unit Los Haitises

The basin of the Yuna River is framed inside the following hydrogeological units:

- Hydrogeological unit No.2: Oriental Mountain range
- Hydrogeological unit No.3: The Haitises
- Hydrogeological unit No.6: Valle del Cibao
- Hydrogeological unit No.7: Central Mountain range

In this work we analyze the hydrogeological aspects related with the hydrogeological unit Los Haitises because this is the one that influences directly in the area of the estuary.

Los Haitises is located in the oriental center of the country and corresponds with the most northern part with a carbonated nature of the mountain of El Seibo, in those a process of advanced karstification has been developed. From a general point of view, it constitutes a traffic area between Valle del Cibao and the Oriental Mountain range, although with some particular characteristics, like the landform with small hills (30 to 40 meters high) called “mogotes” , with altitudes next to 200 meters above sea level.

Los Haitises has a total area of 1823 km^2, from which 80% (about 1462 km^2) correspond to permeable materials and the rest (361 km2) to materials of low permeability. According to the National Hydrogeological Study (2nd Phase), Los Haitises can be divided into five sub-zones and four types of permeable formations or aquifer levels, as well as three formations of low permeability, which has been hydrogeologically classified following reference parameters according to type and permeability UNESCO (1970), and according to the real exploitation potential (superficial and recharge area, geometry, structural conditions, and exploitable resources).

In accordance with this approach, the permeable formations or aquifer levels identified in Los Haitises are the following:

VI.1.1. - Formations with permeability for interstitial porosity

In this first group two sub-groups and three different types of formations can be distinguished:

Porous formations with high permeability and productivity (real exploitation potential)

<u>Qa</u>: <u>Deposits of fluvial terraces from the Quaternary</u>**.** Total area is 70.22 km^2 (that is 4.5% of the total area of permeable materials and 3.85% of the total area of the unit) that are located in the high bed of the Payabo River, Yabón River and La Jagua stream. Their lithology and low cementation confers them a high permeability. They work as a free aquifer, detritic type, with primary permeability for interstitial porosity.

<u>Qal: Deposits of conglomerate, sand and continental molasses from the Quaternary-Pleistocene</u>. Total area is 39.7 km^2 (that is 2.7% of the total area of permeable materials and 2.18% of the total area of the unit) that are

entirely located in the beds of the rivers Payabo-Ara and Chacuey. Their lithology and low cementation confer them a primary permeability for interstitial porosity.

Porous formations with variable permeability and low productivity (real exploitation potential)

Ql: Swamp deposits from Holocene: This is a small area of about 0.29 km^2 (that is 0.02% of the total area of permeable materials and 0.016% of the total area of the unit). They are only located in the northeast sector of the unit.

VI.1.2. - Formations with permeability for fissuration-karstification:

In this second group a single sub-group and formation type has been distinguished:

VI.1.3. - Formations of great superficial extension and high permeability and productivity

Plc: Formation of detritic, reef limestone and very well developed karst from Pliocene-pleistocene, well-known as the limestone of Los Haitises**.** It occupies most of the area of the unit (about 1,352 km^2 that is 92% of the total area of permeable materials and 74.2% of the total area of the unit) and their thickness (estimated) can be 150 m. For its advanced karstification it has been classified with high permeability and considered a free aquifer of the karst type with secondary permeability.

These limestones are arranged on a tract (Plm-y), of low permeability from the Pliocene, denominated in the bibliography like “basal loams of Los Haitises¨ presenting a variable thickness, probably inferior to the 5 meters, and sometimes absent, in which case, those mentioned reef limestones rest on the basal substrate of volcanic-sedimentary rocks.

The limestones of Los Haitises (Plc that constitutes the main aquifer of the unit) as well as the basal loams (Plm-y) are lightly tilted toward the NNO, resting on a Cretacic substrate of low permeability. Toward the west and the north, those limestones enter in contact (and are covered in some sectors) with the permeable quaternary deposits (Qa and Qcg) of the basin of the Yuna, and with the sea in the bay of Samaná.

In their southeast part, the limestones of Los Haitises rise higher and are constituted by tonalites of the not very permeable substrate. In general terms, these limestones arrange lineally from SO to NNE, that makes think that they correspond to a crest of tonalites (of low permeability), almost totally buried under the loams and limestone.

Table 01: Characteristics of the formations

FORMATIONS OF FIRST ORDER	FROMATIONS OF SECOND ORDER	TYPE OF PERMEABLE MATERIAL	AREA (km^2)
Formation with permeability for interstitial porosity	Porous formation with high permeability and productivity	Qa: deposits of fluvial terraces from quaternary	70.22
		Qal: deposits of conglomerate, sands and continental molasses of the Quaternary-Pleistocene	39.7
	Porous formations with variable permeability and low productivity	Ql: deposits of swamps and mangrove from Quaternary-Holocene	0.29
Formations with permeability for fissuration-karstification	Formations of great superficial extension and high permeability and productivity	PLc: detritic reef limestones, very well karst from Pliocene-Pleistocene	1352

Distribution and characteristics of the 5 sub-zones of Los Haitises unit are presented in the hydro-geologic map (see hydro-geologic map). Table 02 summarizes the limits of the sub-units of hydrogeological operation, the formations and aquifer levels integrated in them, as well as their operation limits.

Table 02: Sub-units of hydrological operation, formations and aquifer levels

HYDROGEOLOGIC SUB-ZONES	AREA (km^2)		LIMITS	AQUIFER LEVELS
	PERMEABLE MATERIALS	LOW PERMEABILITY MATERIALS		
WEST (Las Cien Tareas-Cotuí)	231.17	143.71	-North and West: open and in contact with the fluvial quaternary deposits of the Yuna and Chacuey Rivers -East: open and in contact with the fluvial quaternary deposits of the Payabo-Ara Rivers -South: closed, due to the presence of materials of low permeability: Pliocene(PLm-y), rocks plutonic and volcano-sedimentary	-PLc (179.19 km^2) -Qal (28.27 km^2) -Qa (23.71 km^2)
			-North and West: open and in contact with the fluvial	-PLc (362.13 km^2)

NORTH CENTRAL (La Marimba)	399.62	62.65	quaternary deposits of the s Yuna and Payabo-Ara Rivers -East: open and in geometric and lithologic continuity with the reef limestones of the coastal northern area (Naranjo Abajo) -South: closed, due to the presence of plutonic rocks (tonalites) that act as underground barrier.	-Qal (11.45 km^2) -Qa (26.04 km^2**)**
NORTH COASTAL (Naranjo Abajo)	341.19	0.63	-North: open and in contact with the sea (Samaná Bay) -West and East: open and in geometric and lithologic continuity with the reef limestones of the central northern areas and northeast respectively. -South: closed, due to the presence of plutonic rocks (tonalites) that act as underground barrier.	-PLc (341.05 km^2) -Ql (0.14 km^2**)**
NORTHEAST (Sabana de La Mar)	109.43	45.11	-Northeast: open and in contact with the fluvial quaternary deposits of the Yabón River -Southeast: closed, due to the presence of materials of low permeability: Pliocene (Plm-y), plutonic rocks and volcano-sedimentary -West and South: open and in geometric and lithologic continuity with the reef limestones of the noth-coastal and southern areas respectively	-PLc (101.10 km^2) -Ql (0.15 km^2) -Qa (8.18 km^2)
SOUTH (Sabana Grande de Boyá-Los Limones-Loma Clara)	381.06	108.88	-North: open and in geometric and lithologic continuity with the reef limestones of the north-central, north-coastal and notheast areas.	-PLc (368.80 km^2) -Qa (12.27 km^2)
TOTAL	1,462.47	360.99		-PLc (1352.30 km^2) -Ql (0.29 km^2) -Qal (39.72 km^2) -Qa (70.20 km^2)

VI.2. - Inventory of water points of the unit Los Haitises

To obtain this information we used the National Hydrogeologic Study, which is the most recent study. In this work 92 water points have been inventoried whose distribution according to the nature of the point is the following:

- Ten (10) wells.
- Fifteen (15) springs.
- Forty six (46) discharge lagoons or marshes
- Eighteen (18) superficial beds related with the hydrogeological operation of this unit.
- Three (3) other types.

The topographic characteristics of this unit causes that most of their area is practically inaccessible, existing a minimal vial infrastructure, and some reduced population spots located in the borders of this area. Likewise, the abundant vegetation, the karst landscape and the fact that almost the entire unit is inside the limits of the National Park Los Haitises, prevent the development of important agricultural and cattlemen activities, only existing small spots of these activities in the plains that cross the unit or in the borders, where the karst landscape and vegetation are less prominent. This fact is reflected in the nature of the inventoried points, being most of them clearly associated to the karst-type landscape (lagoons and springs), and very few artificial points (wells, etc).

Lacking other water points, it is convenient inventorying lagoons and marshes, since, they provide important information to locate the areas of preferential discharges, and the piezometric levels. This will be fundamental to determine the direction of underground flows. Most of these lagoons are in areas of very difficult access, for what we used topographical maps (scale 1:50,000) to inventory them, being able obtain only their geographical coordinates and places. Additionally a total of 18 water points which are superficial beds related with the hydrogeological operation of the unit have been inventoried. These points provide useful information when characterizing the hydrogeological unit.

The distribution according to use of the inventoried water points is the following:

- 11 domestic supply (10 wells and 1 spring)
- 2 supply to urban areas (2 springs)
- 1 supply and cattle raising (1 spring)
- 8 ecological uses (8 springs)
- 70 without use or unknown (46 lagoons, 18 superficial beds, 3 springs, and 3 other)

VI.3. - Relationship with contiguous units

According to the distribution of the hydrogeological units by PLANIACAS 1989, the units bordering Los Haitises are the following:

- Southeast sector of hydrogeological unit 6: Valle del Cibao
- Northeastern sector of hydrogeological unit 7: Central mountain range

- Northwestern sector of the hydrogeological unit 1: Oriental coastal plain
- Western sector of the hydrogeological unit.2: Oriental mountain range

From a hydrogeological point of view and in relation with the operational limits defined before, the relationship of these hydrogeological units with Los Haitises is the following:

- The whole north sector of the unit (subunits West and Northern Central) is hydraulically connected with the oriental low sector of the hydrogeological unit Valle del Cibao (subunit of the Yuna River) or directly with the sea (Coastal Northern subunit). In general, it is an open border and the main area of discharge of the unit of Los Haitises and takes place by means of sub-aerial springs that arises at level of Valle del Cibao beds or the sea.

  The sub-aerial springs respond, in their majority, to emergencies caused by breaks formed as a consequence of the fracture oriented E-O which conforms the coastal line of the bay of Samaná, to the north of the Pliocene limestone and in contact with the Quaternary deposits of the fluvial net of the Yuna. The different emergencies that take place in this front occur with hydrostatic pressure circulation, because are below the virtual piezometric surface of the limestone. In these areas, a dozen of sectors or emergency points at least are identified, that create small lagoons or marshes areas that discharge in the bed of the Yuna River or in the Barracote River. Belonging to this type of discharge are important, from west to east, the marshes Grande and El Junco, Colorada lagoon, pipe Pontón, Arrequin and Colorado lagoons, the Anegadizos, Guaraguao stream, the pipes Limón and Barraquito, the streams El Cercado and El Vallecito, La Lagunita, the pipe Cristal, Boca de Puerto Escondido and Caño Dulce.

  On the other hand, in the northeast border of the unit (coastal northern subunit) exists a series of springs that discharge directly to the sea whose identification is very complicated, because there is not access from land. Inside this group of springs located almost at sea level, we have identified eight of the most important (we are sure there are more). These are, from east to west: Naranjo abajo, Caseta naranjo, Puerto El Coco, Caletón de Amado or Puerto Amado, Elvedera, Naranjo arriba, La Llana and Manachita.

- The northwest sector of the unit (western border of the west subunit) is connected hydraulically with the northeastern border of the Central Mountain range through the alluvial deposits of the Maguaca River (tributary of the Yuna River). The rest of the contact area with the northeastern border of the unit of the Central Mountain range is closed, because is formed by materials of low permeability (loams and plasters of the Pliocene, Volcano-sedimentary rocks and plutonic rock).

- For the southern border, the unit of Los Haitises is almost hydraulically disconnected from the northwestern sector of the Oriental Coastal plain, because as in the previous case is closed, due to the materials of low permeability (loams and plasters of the Pliocene Volcano-sedimentary rocks and plutonic rocks) that appear and separate geometrically and hydraulically the carbonated materials (Pliocene calcareous) from both hydrological units. Nevertheless of this general underground disconnection, at local level a single connection could take place to the south of Antón Sánchez, among the town Los Cerritos and Sierra de Agua, where geometric continuity exists among the Pliocene calcareous (PLc) of Los Haitises and the deposits of Quaternary alluvial (Qa) of the head of the Comate River.

- Something similar happens, for the oriental border of the unit of Los Haitises, in their contact area with western sector of the Oriental Mountain range. The presence of materials of low permeability (loams and plasters of the Pliocene, Volcano-sedimentary rocks and plutonic rocks) hydraulically disconnect both units, except in the northeast sector, where the carbonated materials (Pliocene calcareous) of Los Haitises enter in geometric and hydraulic contact with the deposits of alluvial quaternary (Qa) of the left riverbank of the low basin of the Yabón river. In this area a series of wall springs are located, like those of the Loma del Fresco hill and the Chiquito river, located at 15 and 10 meters above sea level.

- Finally, the hydrological unit of Los Haitises does not present any type of geometric or hydraulic connection with the bordering units, because its basal substrate is always formed by materials of low permeability (loams and plasters of the Pliocene, Volcano-sedimentary rocks and plutonic rocks)

VI.4. - Relationship with superficial beds

The hydrological net related with Los Haitises is defined for three axes and sectors of discharges:

- The axis of predominant distribution SSO-NNE is located in the western sector of the unit (area called Las Cien Tareas in Sabana Grande de Boyá). It is the one in which the rivers that rise outside of the unit (in the sector La Naviza) fits in her and cross it in some sectors (Río Payabo-Ara), while in others (such as Cevicos River) they infiltrate in the limestone and arise again in their north flank (sector called El Atoro, Los Peinados and Guaraguao)
- The axis of determinant distribution N-S is located in the southern sector of the unit (area called Antón Sánchez-Los Limones), in which the hydrographic net rises in the southern border of the unit (in the contact area between the Pliocene calcareous and the loams) and discharges toward the left riverbank of the Ozama River (Boyá, Sabana and Comate rivers) outside the unit of Los Haitises.
- The axis of predominant distribution S-N is located in the oriental sector of the unit (area called San Rafael, La Radera, Yanigua and Cuba Libre), in which the hydrographic net rises in the border of the unit and discharges in direction Southwest-northeast and south-north toward the left riverbank of the Yabón river (Yanigua River and La Jagua stream).

This drainage net has had a big incidence in the pluviometry of the aquifer whose more prominent characteristics are the following:

The hydrographic division north-south on the limestone of Los Haitises is located very next to the south border, estimating that less than the 20–25% of these belong to the south basin (Yabacao–Ozama). This fact and the tilt toward NNO of the limestone suggest that most of the underground flows will go directed toward the north.
The north division has three basins or ¨hydrographic zones” from west to east, which are the following:

- The one of Yuna River and their tributaries: Chacuey, Cevicos and Payabo-Ara Rivers (west and northern central sub-zones).
- An oriental center part of calcareous origin that discharge in the sea (northern coastal sub-zone).
- The oriental end of the limestone, belonging to the basin of the Yabón River (northeast sub-zone).

The west sub-zone is related with two discharge axes (Chacuey and Cevicos) that are originated upper lands of the unit. The Chacuey River crosses this sub-zone in direction SSE-NNO and acts like a drainage river, mainly in its low portion. On the other hand, the Cevicos River infiltrates all its flow in the limestone, in the western sector between the small towns Primera Boca and Consumidero, making a clear example of open absorption of drain (sumidero??) type. In its underground circulation through the limestone of this subunit drains or gains a flow of about 400 liters per second (average for October 2003 and September 2004) that discharges in the north border of the unit (sector called La Alcantarilla).

In the northern central sub-zone the limestone of its western sector is crossed by the Payabo River (affluent of the Yuna for its right margin), and contact, to the west and to the north, with the quaternary deposits of the Yuna. The Payabo River begins to cut the base from the limestone at about 35 m. The quaternary deposits of the Yuna are about 40 m and less than 20 m (to the west and the north of the area respectively). The lowest points in the limestone are, therefore in their north border. This river will work as a drainage river with regard to the unit of Los Haitises and through it (mainly through its lower tract) some of the underground resources of this sub-zone will be discharged (about 3,000 liters per second on average for October 2003 and September 2004).

The northern coastal sub-zone descends from the 350-467 meters above sea level of the south north division to the coast in the Samaná bay. There are not superficial beds in this area and all the useful rain infiltrates in the limestone, discharging directly to the sea, by means of a series of springs already commented previously.

The northeast sub-zone has the smallest extension and discharge area that the rest of the sub-zones of the unit. The base of the limestone descends toward the north, from the 200 to 80 meters above sea level, then entering in contact (less than 40 m), with the quaternary deposits of the Yabón River. Through these deposits (and for the heads of Yanigua and La Jagua Rivers) discharge about 1200 liters per second (average for October 2003 -September 2004).

In the southern sub-zone, the base of the limestone is over the 200 meters above sea level. The tilt toward the NNO of the limestones and the fact that more than 75-80% of its discharge area “belongs¨ to the north basin, suggest that most of the underground flows of the calcareous are directed toward the north. We think that the west and northern central sub-zones are equal in surface and importance, while the northeast area is much smaller.

Due to the distribution of the altitudes and the tilt of the limestones we think that the underground hydrographic division among the Coastal and Southern Northern sub-zones will be lightly displaced toward the south, regarding the superficial division (except to the east, where the tonalites substrate will suppose a barrier in depth to the flows, and will make that both hydrographic divisions are coincident). In the border of this subunit (and in the contact area between the Pliocene calcareous and the substratum margo-yesifero) about thirty sub-aerial springs generated (emergent type) like discharge lagoons above the level of the superficial beds. In their majority they are identified in the sheet 6272 I, Antón Sánchez and in the sectors of Sabana del Medio (lagoons Mareys, Ortiz, Piedra, Sabaneta, Rincón Grande, Los Pomos, Sotero and Pensadiso), Sabana de los Javieles (lagoons Cortadera, Sabaneta and Los Flacos), Los Callejones (lagoons Las Guáranas and Corralito) and LomaClara-Los Callaillos (lagoons Orlean, Clara, Los Hicacos and Prien). In these sectors they are located with contact structures at 180 to 250 meters above sea level (most around 190-200 meters) and coincident with the contact area between the bases of the reef calcareous (PLc) and the basal loams (PLm-y) or the volcano-sedimentary rocks (RVS). Their circulation is usually free (typical of superficial and well evolved karst) and with multiple emergencies that indicate very tight fissuration.

VI.5. - Estimation of the underground hydric balance

Data used here comes from values presented by the company EPTISA in the National Hydrogeologic Study.

At the present time, the underground hydric balance for the hydrogeological unit Los Haitises can just be estimated or presented in a very preliminary way. This is because the basic parameters for quantification are not known enough with the necessary accuracy. Such parameters include the effective infiltration in the different permeable and aquifer formations, the total underground discharges to the fluvial beds, the possible connections with contiguous units and the storage variation or reservations.

Nevertheless of the mentioned limitations, we present a tentative hydric balance based on the available historical data and on the values recorded during this study, for which the classic equation of the hydric balance was used:

Entrances–Exits–Storage Variation (reserve) = Closing Error

Since this is an underground hydric balance that ignores storage variation (because there is not information on the geometry of the aquifers in depth and on the historical evolution of their saturated areas) we have only considered the following terms of the underground balance:

Entrances

- IP: Infiltration or recharge in land coming from precipitation on permeable surfaces.
- IRC: Infiltration or recharge coming from superficial waters (rivers, streams and lagoons).
- IRR: Infiltration or recharge from irrigation returns and infiltrations of channels.
- QAC: lateral and underground entrances coming from adjacent zones or hydrological units.

Exits

- DR: Discharges of underground waters for superficial beds.
- QM: Exit of underground water for springs and emergencies of different types: sub-aerial and submarine.
- QS: Exit of underground water for connection with bordering units.
- B: Underground extractions of waters for pumping.

In order to establish the limits of the regions or zones for hydric balance analysis, we used those the two levels hydrological operation presented in the previous sections: the hydrogeological unit and the hydrogeological sub-units. This way we could apply in an easy way the quantifications of recharges and discharges included in the section of hydrogeological operation and obtain the terms of entrances and exits of the balances (because correspond to areas of hydrogeological operation similar characteristics).

As interval of time for the hydric balance presented we used two types:

- Inter-annual: For intervals of several typical hydrological years of the available historical series (dry, medium and humid years).
- Annual: For the control hydrological year of this study (October 2003 September 2004)

Finally, we used as units for the balance: hm^3 /year, because this is the most appropriate unit for the volumes managed in the intervals and periods of time used.

Inter-Annual Balance

We have considered that it is interesting establishing estimative balances for intervals of several typical hydrological years of the available historical series (dry years, medium and humid) as a reference for possible planning of underground resources of the unit. Additionally, when using intervals of several years, the possible changes in the storage will have a smaller incidence in the equation of the balance, comparing with other terms of equation.

These hydric underground balances, as we said before, only respond to estimative and proportional calculations in function of the following parameters: recharge area (of permeable materials) of each sub-unit, data on useful rain, percentages of underground run-off of this useful rain, historical and measured gauging data and extractions. The description of the methodology and the different volumetric estimations applied to each of the mentioned parameters have already been included in the climatology sections, gauging and hydrological operation (recharges and discharges).

On the other hand, the terms hardly quantifiable in a direct way (such as the connections with bordering units and discharges to the sea) will be estimated as a difference in the balance equation and will only be established with more precision when, in the future, enough data on the effective infiltration in the different permeable and aquifer formations, total underground discharges to the fluvial beds, the possible connections with contiguous units and the variation of the storage or reservations in the different aquifer formations, are available.

The establishment of the modules of type years (dry, medium and humid) for the whole hydrogeological unit is complex, due to the climatic differences that exist from a sector to another inside the unit. The modules have been established, therefore, for each of the three climatic stations with historical data that we used. Although this climate heterogeneity (analyzed in detail in the section on climatology), we have established some average limits as reference for every type year, the same that have been used for the establishment of the inter-annual balances.

Dry years

According to the climate study carried out for this hydrogeological unit “dry years” are those with average annual pluviometry is not over 1350 mm. The balance of underground waters for this dry years (with average data), is as follows:

Entrances

Table 03: Balance of underground waters for dry years (entrances)

SUB-UNITS	INFILTRATION RAIN (IP)	INFILTRACIÓN BEDS (IRC)	RETURNS IRRIGATION (IRR)	LATERAL ENTRANCES (QAC)	LATERAL ENTRANCES
WEST	30	15			45
NORTH CENTRAL	52				52
NORTH COASTAL	44				44
NORTHEAST	14				14
NORTH	50				50
TOTALS	**190**	**15**			**205**

* All data are in hm^3/year

Exits

Table 04: Balance of underground waters for dry years (exits)

SUB-UNITS	DISCHARGE TO RIVERS (DR)	SPRING AND LATERAL CONNECTIONS (QM+QS)	EXTRACTIONS FOR PUMPING (B)	TOTAL EXITS
WEST	35	8	2	45
NORTH CENTRAL	21	30	1	52
NORTH COASTAL		44**		44**
NORTHEAST		13	1	14
NORTH		48	2	50
TOTALS	**56**	**143**	**6**	**205**

*All data are in hm^3/año ** Direct discharge to the sea

Medium years

According to the climate study carried out for this hidrogeológical unit “medium years” are those with average annual pluviometry is between 1350 y 1800mm. The balance of underground waters for this “medium years” (with average data), is as follows:

Entrances

Table 05: Balance of underground waters for medium years (entrances)

SUB-UNITS	INFILTRATION RAIN (IP)	INFILTRATION BEDS (IRC)	RETURNS IRRIGATION (IRR)	LATERAL ENTRANCES (QAC)	LATERAL ENTRANCES
WEST	63	33			96
NORTH CENTRAL	109				109
NORTH COASTAL	93				93
NORTHEAST	30				30
NORTH	104				104
TOTALS	**399**	**33**			**432**

* All data are in hm^3/year

Exits

Table 06. Balance of underground waters for medium years (exits)

SUB-UNITS	DISCHARGE TO RIVERS (DR)	SPRING AND LATERAL CONNECTIONS (QM+QS)	EXTRACTIONS FOR PUMPING (B)	TOTAL EXITS
WEST	81	13	2	96
NORTH CENTRAL	40	68	1	109
NORTH COASTAL		93**		93**
NORTHEAST		30		30
NORTH		102	2	104
TOTALS	**121**	**306**	**5**	**432**

*All data are in hm^3/year * * Direct discharges to the sea

Humid Years

According to the climate study carried out for this hidrogeológical unit “humid years” are those with average annual pluviometry is over 1800 mm. The balance of underground waters for this “humid years” (with average data), is as follows:

Entrances

Table 07: Balance of underground waters for humid years (entrances)

SUB-UNTS	INFILTRATION RAIN (IP)	INFILTRATION BEDS (IRC)	RETURNS IRRIGATION (IRR)	LATERAL ENTRANCE S (QAC)	LATERAL ENTRANCE S
WEST	138	70			208
NORTH CENTRAL	239				239
NORTH COASTAL	204				204
NORTHEAST	65				65
NORTH	227				227
TOTALS	**873**	**70**			**943**

* All data are in hm3/year

Exits

Table 08: Balance of underground waters for humid years (exits)

SUB-UNITS	DISCHARGE TO RIVERS (DR)	SPRINGS AND LATERAL CONNECTIONS (QM+QS)	EXTRACTIONS FOR PUMPING (B)	TOTAL EXITS
WEST	177	30	1	208
NORTH CENTRAL	99	140		239
NORTH COASTAL		204**		204**
NORTHEAST		65		65
NORTH		226	1	227
TOTALS	**276**	**665**	**2**	**943**

*All data are in hm^3/year * * Direct discharges to the sea

VII. – Conclusions

According to all information gathered from several sources and exposed in this work we conclude that the high and medium basin of Yuna river presents the following characteristics:

- The climate is very varied, since in the head of Blanco River very low temperatures are registered due to its proximity with the hill Alto Bandera; while in northern mountain range the temperature is higher, reaching extremely high values.
- With relationship to precipitation, this is one of the most humid basins in the country and the Yuna River the biggest (caudaloso) of this part of island Hispaniola; with areas with precipitations over 3000 mm/year, but with a great variation since this value can go down to 1000 mm/year.
- In the high area its main tributary is Blanco stream, while in the medium part, the three main tributaries are Masipedro, Maimón and Camú.
- The flows of the Yuna in its medium area are bigger than in its high area, due to the flowing contribution of its different affluents.
- The run-off from the for the medium area observed in the control stations is 30.17 m^3/s, and the lowest flows are registered in January-April and August-November.
- In the basin there are 6 dams already built, two in construction process and six in study process, considering that in Piedra de los Veganos a complex will be built that will consist of five reservoirs.
- With regard to the hydrogeological aspects, the basin is framed inside four hydrogeological units (Oriental Mountain range, Los Haitises, Valley del Cibao and Central Mountain range).
- Two permeable formations or aquifer levels of first order and three of second order are identified.
- The sources or water points that influence the medium and low basin are wells, springs, lagoons and superficial beds.
- The topographic characteristics of the unit of Los Haitises (low basin) cause that most of their surface is practically inaccessible with a minimum vial infrastructure.
- The underground flows toward the estuary go in northwest-southeast direction from the vicinity of Sánchez and south-north from the vicinity of the lagoon Cristal.
- The Cevicos River infiltrates all its flow in the limestone located between the small towns Primera Boca and Consumidero of the province Sánchez Ramírez. Its underground circulation through the limestone drains a flow of about 0.4 m^3/s.
- The Payabo River works like drainage river with a flow of approximately of 3.0 m^3/s.
- The northern coastal sub-zone of the unit descends from the division north-south to the sea level at Samaná Bay. There are not superficial beds and the total useful rain infiltrates in the limestone, discharging directly through a series of springs.
- In the northeast by the heads of Yanigua and La Jagua Rivers drain about 1.2 m^3/seg., through the limestone deposits.
- The underground flows in the southern area go toward the north through the limestone.