PROBLEMATIC HYDRIC-ENVIRONMENTAL OF THE CONSTRUCTION OF THE HYDROELECTRIC DAM “EL CIMARRÓN” EL SALVADOR, C.A

Julio César Quiñónez Basagoitia
Hydrologist Consultant
for the Department of Environmental and Natural Resources (MARN)
e-mail: julioquinonezb@gmail.com

ABSTRACT

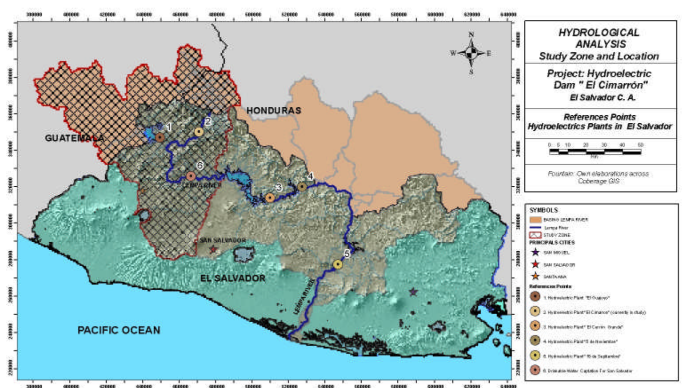
This document brings together the essential aspects of the hydrological study carried out to determine the impact on the strategic hydric resources of the northern zone of El Salvador, due to the planned construction in the year 2009 of the “El Cimarrón” Hidroelectric Dam on the River Lempa country’s principle river, the hydrographic basin of which, extends to the neighbouring countries of Guatemala and Honduras. This investigation, which was realised as a specific component, within the framework of Environmental Impact Study, which is required for the official approval of the Project by the Ministry for the Environment and Natural Resources (MARN), and with the purpose of defining the viability or environmental unsuitability of the project; had as its fundamental purpose the determination of the environmental flows and development the evaluation of the hydrological behaviour of the river, with the aim of establishing the implications and levels of affectation on the hydric system, with the implementation of the Hydroelectric Project. In order to do so, the determination of the mean flows at different points was carried out, by means of equations of regionalization, factors of the relation “precipitation-runoff” and application the hydrological modelling system MIKE 11; later establishing the environmental flows, as a percentage of the calculated mean flows. In the conclusions are emphasised the effects and severe impacts on the fluvial system of the river and on the preservation of the hydric resources, which would be brought about by the implementation of the project, expressed primarily in a significant reduction in the actual hydric disposability for the different uses, among which, the essential use is the supply of water to ample sectors of the population of San Salvador, the capital of El Salvador

Keywords/Key Terms: Environmental flows, hydrological behaviour, means flows, hydric resources, hydric disposability, impact on hydric resources, Environmental deteriorate.

INTRODUCTION

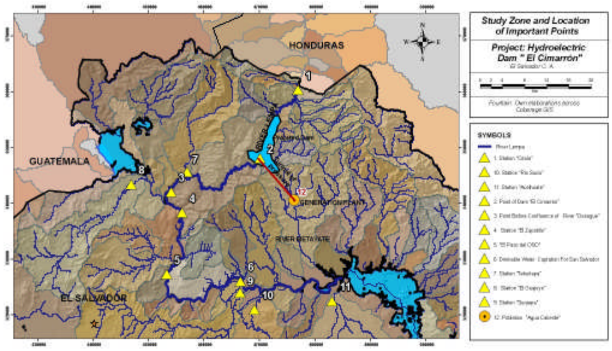
The River Lempa constitutes El Salvador’s principal river and its hydrographic basin has an extension of 18,246 km^2, of which approximately 30% is found in Honduras, 14% in Guatemala and 56% in El Salvador.
The area of study pertenent to the “El Cimarrón” Hydroelectric Project is located in the subdivision known as the “upper basin” of the hydrographic basin of the River Lempa, whose extension, with regard to the hydric catchments area, reaches an area 7,354 km^2, from its maximum elevation in the countries of Honduras and Guatemala, as far as the neighbourhood of the Cerrón Grande reservoir as shown in Map 1.

Map 1



The River Lempa enters Salvadorean territory in the neighbourhood of the village of Citalá where the extension of the hydric catchments area at this point, as determined by the hydrometric station “Citalá” (1), is 914 Km^2. This first point of importance indicated by the numeral (1), along with the other points of importance in the zone of study, is numerically correlated in the form expressed in Map 2.

Map 2



At the “Citalá” station a mean annual flow in the order 19.89 m^3/s has been determined, along with mean seasonal flows, in the order of 4.53 mt^3/seg in the dry season (November-April), and 35.24m^3/s in the rainy season (May to October), defined for the period 1972-2006 with interruptions in the 1980s

From this point it is proposed to develop the “reservoir” upstream, while at the same time developing, the take from the diversion of the regulated flows to the generation plant, which it is intended to locate in the neighbourhood of the village of Agua Caliente (12), with an estimated elevation of 305 meters over level sea (mols)

The turbinated flows will discharged into the River Metayate, and will oscillate in the order of 35 mt^3/seg – 82 mt^3/seg according to the projected requirements of potential and generated energy.

The conduction piping or pressure túnel would have a length 8.4 km approximately. In accordance with the difference in elevation between the plant and the water table of the reservoir, the generation load could oscillate between 385 and 392 mts. Under these conditions, the El Cimarrón Hydro-electric project could dispose of a potential between 115 Mw for low flows and 260 Mw for high flows. A typical scenario for the operation of the reservoir destined for the generation of energy, is presented within the section concerning results.

At the dam-point (2), mean flows between 2.55 mt^3/seg - 23.90 mt^3/seg were obtained during the dry season, along with mean flows of 5.71 mt^3/seg – 83.25 mt^3/seg m3/s during the rainy season, calculating with it, an annual mean flow of 29.75 mt^3/seg.

From this Dam-point (2), a sudden reduction of said system of natural flows should be expected, giving rise to the presence of “environmental flows” regulated by the operation of the reservoir, which in the study of the pre-factibility of the project were initially established as in the order of 3.0 mt^3/seg for all months of the year. These flows would not have a significant increase upstream to the confluence with the River Desague (3), because arise from this point, the environmental flows can increase periodically due to the contribution of the River Desague, whose flows arise from the generation of the Guajoyo Hidroelectric Dam. However, this contribution is not very significant during certain hours of the day, due to the fact that the dam is not operational in these hours, with the result that its discharge is significantly reduced.

Subsequently, the River Lempa continues to increase its flows with the contribution of the tributary basins, passing through the points of the hydrometric stations “Zapotillo” (4) and “Paso del Oso” (5) until reaching the point of captation and treatment of drinking water for the supply of San Salvador (6), which constitutes one of the points of greatest importance in the evaluation of this study.

METHODOLOGY

I. Determination of Mean Flows

The hydrological analysis carried out for the determination of mean flows at the various points of importance along the length of the channel of the River Lempa, was carried out through the application of regionalization equations and areal relations between precipation and runoff, taking into account the hydrologically homogenous regions previously defined for El Salvador. Both methodologies were developed by the National Service for Territorial Studies (SNET) for the purposes of the development of the Dinamic and Integrated Hydric Balance of El Salvador (December 2005).

In addition, for the analysis of mean flows at the Citalá Hydrological Station (1) and the Dam Point (2), as indicated in Map 2, the calibration and simulation of mean flows was carried out, by means of the hydrological model rain-runoff HBV system MIKE 11, which constitutes a valuable tool for hydrological analisis, and which was developed by the Swedish Meteorological and Hydrological Institute (SMHI). This was employed, as an additional resource, within the framework of the project "*Analysis of the Situational State of the Hydric resources in the Northern Zone of El Salvador" (March 2007),* supported by National Commission for Development (CND) and the United Nations Development Programme (UNDP), in cooperation with the National Service for Territorial Studies (SNET), which is the proprietor of the model.

Regionalization of Means Flows is a methodology, by means of which were established the relations between mean flows and the area of the respective basins, along with the factors of monthly distribution for mean flows in accordance with the hydrologically homogeneous regions. Square 1 lays out the equations for the estimation of mean annual flows in accordance with the hydrologically homogeneous regions defined in map 3, along with the factors of the monthly distribution of the annual flows, which present in square 2

Square 1 Equations of regionalization of mean annual flows and monthly distribution factors.

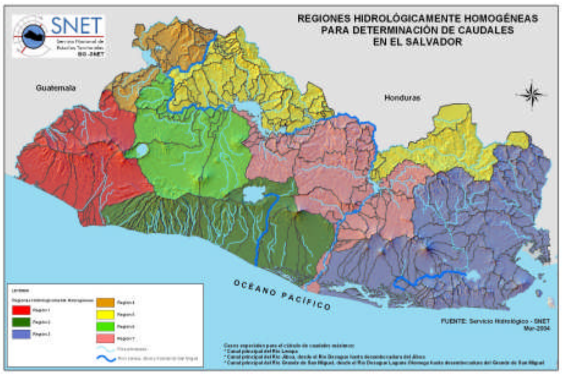
REGIÓN	ECUACIÓN	R^2	RANGO DE AREA (Km^2)
1	$Q = 0.0127 * A + 1.4954$	0.9842	100 – 1991
2	$Q = 0.0103 * A + 0.4433$	0.9055	55 – 430
3	$Q = 0.0151 * A + 0.4752$	0.964	100 – 2240
4	$Q = 0.0109 * A + 0.545$	0.9647	25 – 587
5	$Q = 0.0304 * A - 0.3231$	0.8621	45 – 185
6	$Q = 2E\text{-}06 * A^2 + 0.0156 * A + 0.0944$	0.9626	34 - 845
7	$Q = -1E - 05 * A^2 + 0.0214*A - 0.2597$	0.8932	13 – 560

Where A = area of the basin in Km2
Mean annual water flow in m3/s

Square 2 Factor of Monthly Distribution

ZONA	ENE.	FEB.	MAR.	ABRIL	MAYO	JUNIO	JULIO	AGO.	SEPT.	OCT.	NOV.	DIC.
1	39.70	36.07	35.19	41.08	70.13	143.57	134.66	160.26	235.02	189.34	72.12	**42.86**
2	27.83	21.63	19.70	19.57	36.30	103.05	117.51	189.77	298.52	244.10	78.82	**38.88**
3	15.60	11.72	10.37	13.04	51.07	165.84	105.23	131.49	308.94	298.19	65.10	**23.43**
4	12.71	12.05	11.62	12.93	37.37	187.87	167.96	196.26	295.08	209.56	37.34	**19.24**
5	11.33	8.41	7.91	11.48	39.99	187.45	151.65	181.47	323.98	210.04	44.41	**16.62**
6	49.55	46.97	44.99	47.87	67.07	123.54	151.70	171.84	218.65	153.68	70.02	**54.11**
7	27.35	23.68	22.55	25.14	42.06	147.12	130.26	164.56	297.01	220.13	67.01	**33.14**

Map 3



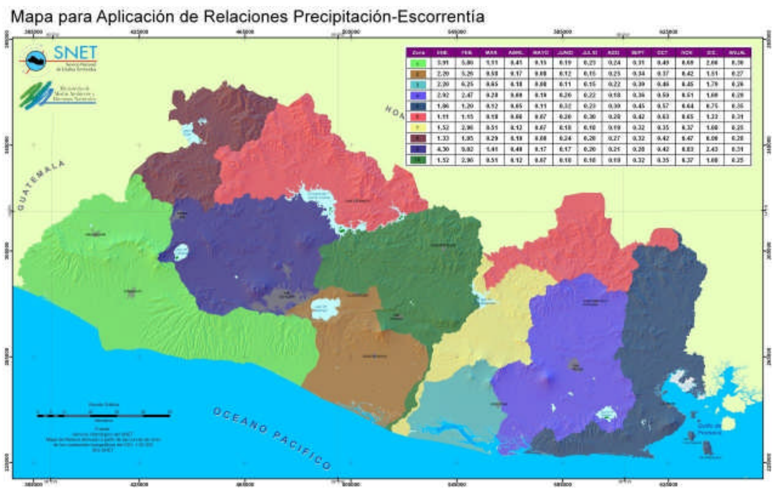
It should be mentioned that the equations of regionalization present a range of validity in so far as the area of the basins in accordance with t information by which they where generated, with the result that with respect to basins which are outside the of area where the equations are valic not possible to apply this methodology.

SNET developed the second methodology based on factors arisen from the relation rainfall-runoff.
The selection of the methodology employed for the generation of the runoff in the various basins, was determined by the area of the basins and the evaluation of the results of both methodologies in each individual case.
The second methodology used for the generation of runoff, was the relation Precipitation-Runoff in which were analyzed the existent relations on a monthly level of these two variables. The precipitation taken into account in the relation corresponds to the mean monthly precipitation and the drainage to that registered in the hydrometric stations, but in units of mm. On the basis of these relations were determined the factors relating the two variables, in accordance with the that presented in the map in square 3 and map 4

Square 3 factors the relation between precipitation and drainage

ZONA	ENE.	FEB.	MAR.	ABRIL	MAYO	JUNIO	JULIO	AGO.	SEPT.	OCT.	NOV.	DIC.	ANUAL
1	3.91	5.86	1.11	0.41	0.15	0.19	0.23	0.24	0.31	0.49	0.69	2.06	**0.30**
2	2.20	5.26	0.58	0.17	0.08	0.12	0.15	0.25	0.34	0.37	0.42	1.51	**0.27**
3	2.20	6.25	0.65	0.18	0.08	0.11	0.15	0.22	0.30	0.46	0.45	1.79	**0.26**
4	2.92	2.47	0.28	0.09	0.10	0.20	0.22	0.18	0.36	0.50	0.51	1.09	**0.29**
5	1.86	1.20	0.12	0.05	0.11	0.32	0.23	0.30	0.45	0.57	0.64	0.75	**0.35**
6	1.11	1.15	0.18	0.06	0.07	0.20	0.30	0.28	0.42	0.63	0.65	1.23	**0.31**
7	1.52	2.96	0.51	0.12	0.07	0.18	0.18	0.19	0.32	0.35	0.37	1.08	**0.25**
8	1.33	1.05	0.29	0.10	0.08	0.24	0.28	0.27	0.32	0.42	0.47	0.90	**0.28**
9	4.30	9.02	1.41	0.40	0.17	0.17	0.20	0.21	0.28	0.42	0.83	2.43	**0.31**
10	**1.52**	**2.96**	**0.51**	**0.12**	**0.07**	**0.18**	**0.18**	**0.19**	**0.32**	**0.35**	**0.37**	**1.08**	**0.25**

Map 4 Map of the relation between precipitation and drainage



II . Determination of the Ambient Flows

The Environmental flows are essential for the maintenance of the minimum conditions necessary for the preservation of the fluvial and riverside ecosystems, along with the maintenance of biodiversity and natural habitats, the flows required for the dilution and control of contamination, the aquatic systems, the hydromorpho-lithological conditions, and the equilibrium of the dynamic interconnections between the surface and subterranean waters. In addition, they carry out an essential function in guaranteeing the minimum requirements of the diverse human uses: the supply of water for consumption, irrigation, eco-tourism, productiv exploitation, etc.

For the purposes of the calculation of Environmental flows, there exist various methodologies that integrate diverse variables of analysis and procedure, in accordance with the specific purposes of the investigation. Among these methods are: Hydrodinamic Methods, Methods of Functional Analisis, and Habitat Methods. In general, these methodologies conceive the total river-bed as a structural unity in which the hydro-biological and hydraulic dynamics of the river, are encountered in direct interaction with natural habitats and its geo-morpholoy. The same methodologies require the use of computational models, topographic sections of the river, and the determination of variables of hydro-dynamic correlation with the essential aspects of the fluvial and riverside ecosystems. In such an analisis there is a tendency towards the participation of a multi-disciplinary team of experts which constitutes an ample body of investigation and hydro-biological modelling.

Due to the same range of hydrological analisis, there was carried out in the present study, a first approximation of the regimen of environmental flows, realised by means of “Hydrological Indices”, where the environmental flows are established as a percentage of the mean flows.

These methodologies have been established on the basis of practical norms based on the percentages of flows or hydrological indices, employed where ecological data do not exist or are very scarce. These indices proceed from generalized observations concerning hydro-ecological relationships or else from more formal data derived from specific investigation with a concrete ambit.

- Fishing Law

  Establishes an environmental flow as 10% of the annual mean flow (Q mean)
- Indice Q95

  Used in England and is defined as the flow which is reached or exceeded 95% of the time and is frequently used in the company of ecological data.
- Swiss Legislation Q347

  Defines the ecological flow as that which is exceeded on 347 days a year
- Tennant Method

An index developed in the U.S.A by means of the employment of data arrived at by the calibration of hundreds of rivers, with the aim of determining the characteristic flows of a healthy river environment, characteristic of the preservation of flora, fauna, the geomorphology of the river, water quality, and the fluvial ecosystems.
In terms of percentages of average flows per annum it defines

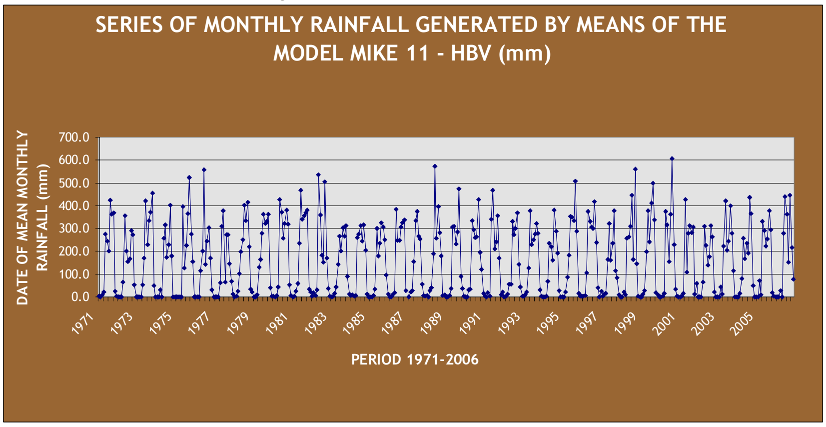
10% as sufficent for a regular fluvial environment or for surival;
30% as sufficent for a satisfactory fluvial environment;
60% as sufficent for an excellent fluvial environment.

Taking into account these particular focuses, for the purposes of the present study the following percentile distribution was applied: for the dry season, 35% of the mean monthly flow for the months of the dry season understood as the months of November through to April; and for the rain season, a range of 34%-60% of the mean monthly flow obtained in the months of the rainy season understood as the months of May-October.
This distribution corresponds to a better simulation of mean monthy river regimen than that derived from the lineal distribution proposed initially in the factibility study which established a environmental flow equivalent to 10% of the mean annual flow for all months of year.

RESULTS

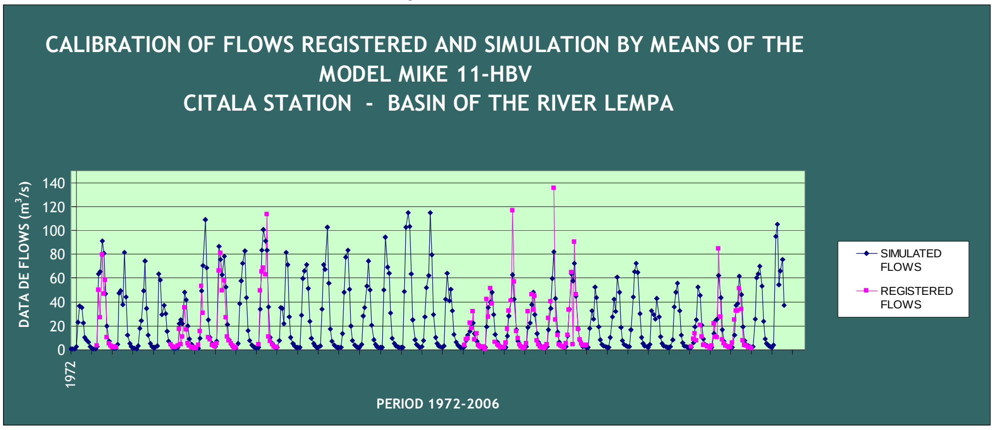
The calculation of the mean flows at the Citalá Station was realised on the basis of its historical records of mean flows. In addition the hydrological analysis was carried out by means of the calibration and simulation of the flows applying the MIKE 11-HBV system, with which a new series of mean flows was obtained at said station. In doing so, incident meteorological stations in the basin were utilised, thereby attaining a distribution of precipitation as expressed in Graph 1.

Graph 1 Monthly areal rainfall at the Citalá Station



Subsequently the calibration and simulation of mean flows at said station was carried out, thus determining the behaviour of mean monthly flows as expressed in Graph 2.

Grafph 2 Calibration of monthly mean flows at the Citalá Station



In Table 1 is presented the resultant average series of mean flows calculated by means of the historical registers and by means hydrological modelling, obtaining a mean annual flow of 19.89 m3/s and 24.11m3/s respectively.

Tabla 1

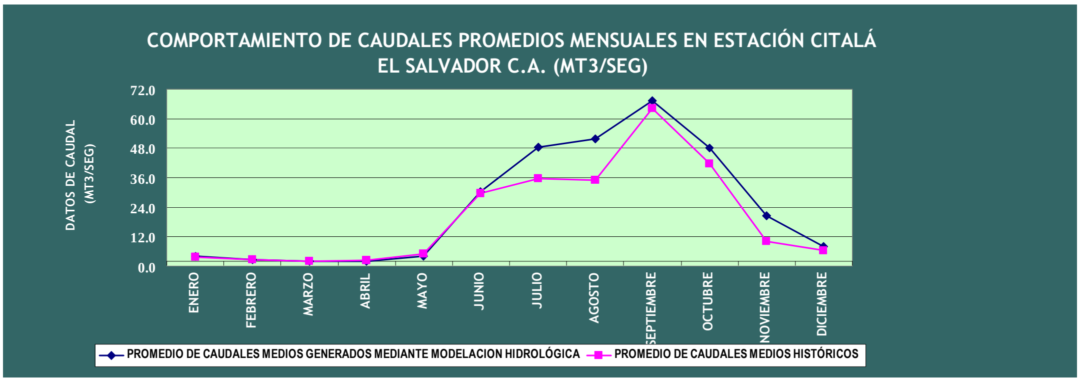
HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A
MEAN FLOWS CALCULATED BY HYDROLOGICAL MODELING AND BY MEANS OF HISTORICAL RECORDS IN CITALA STATION

METHOD OF CALCULATION OF MEAN FLOWS	Area (Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Method of calculation
Mean flows determinated on the basis of historical records	914	3.75	2.54	1.91	2.46	5.04	29.56	35.70	35.07	64.25	41.85	10.08	6.45	19.89	HR
Mean flows determinated on the basis of hydrological model HBV	914	4.17	2.64	2.01	1.94	4.00	30.25	48.52	51.69	67.25	48.06	20.55	8.21	24.11	HBV

Note: Determination of flows* = Hydrological Modeling: HBV
Historical Records: HR

Graph 3 presents the behaviour of the mean flows at the Citalá Station, as established by means of both methods.

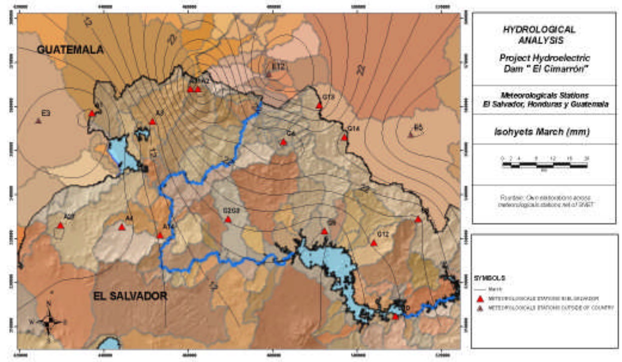
Graf. 3



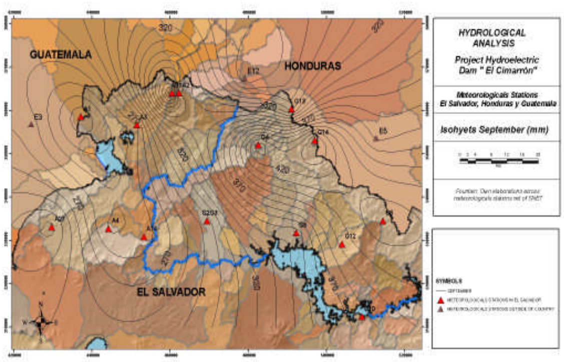
Subsequently the calculation of the mean flows at the Dam Point was iniciated parting from the results obtained for the Citalá Station. For this purpose, the mean flows at the Citalá Station were calculated by means of hydrological modelling, which integrates, in the rainfall analisis, a broad degree of meteorological information. This could be more appropriate than to consider the series of registered mean flows, which have been registered for a limited number of years.

Starting with the Citalá station, the calculation of the different series of mean flows arising from the various adjacent sub-basins which contribute to the flux of the River Lempa as far as the Dam Point was iniciated. These series were calculated by means of the methodology of the relationships between precipitation and runoff. For this purpose, the distribution of rainfall for each month was developed by means of the tracing of isohyets, as presented in Maps 3 and 4.

Map 3 Isohyets March



Map 4 Isohyets September



Through the application of this method and the series of monthly precipitation, calculated for each sub-basin by means of the tracing of isohyets, the results presented in Table2 were obtained. Subsequently in Table 3 the final series of mean monthly flows is presented for each of the sub-basins encountered between the Citalá Station and the Dam Point. In said Table 3 it can be observed that the mean annual flow at the Dam Point is in the order of 29.75m3/s.

Tabla 2

MEAN FLOWS CALCULATED BY THE METHOD "PRECIPITATION - RUNOFF" FOR THE BASINS LOCATED BETHEEN CITALÁ STATION AND DAM POINT

PRECIPITATIONS CALCULATED BY ISOHYETS (PERIOD 1972 - 2006)

Basins	area (km^2)	Jan	Feb	Mar	April	May	Jun	Jul	Ago	Sept	Octb	Nov	Dec	annual
Nunuapa (Región 6)	112.15													
Precipitation (mm)		22.50	8.50	24.00	68.50	217.50	410.00	262.00	322.00	410.00	204.00	42.00	8.50	1999.50
Factors of P-R.		1.11	1.15	0.18	0.06	0.07	0.20	0.30	0.28	0.42	0.63	0.65	1.23	0.31
Runuff (mm)		24.98	9.78	4.32	4.11	15.23	82.00	78.60	90.16	172.20	128.52	27.30	10.46	647.64
Runuff (m^3/s)		1.05	0.45	0.18	0.18	0.64	3.55	3.29	3.78	7.45	5.38	1.18	0.44	2.30
Sapuapa (región 6)	40.02													
Precipitation (mm)		8.70	9.50	23.80	76.50	225.80	395.00	273.00	346.50	382.50	245.00	50.70	12.80	2049.80
Factors of P-R.		1.11	1.15	0.18	0.06	0.07	0.20	0.30	0.28	0.42	0.63	0.65	1.23	0.31
Runuff (mm)		9.66	10.93	4.28	4.59	15.81	79.00	81.90	97.02	160.65	154.35	32.96	15.74	666.88
Runuff (m^3/s)		0.14	0.18	0.06	0.07	0.24	1.22	1.22	1.45	2.48	2.31	0.51	0.24	0.84
De Tiano (región 6)	3.78													
Precipitation (mm)		22.20	9.00	20.50	62.00	190.00	360.00	232.00	280.00	331.00	176.00	47.00	15.50	1745.20
Factors of P-R.		1.11	1.15	0.18	0.06	0.07	0.20	0.30	0.28	0.42	0.63	0.65	1.23	0.31
Runuff (mm)		24.64	10.35	3.69	3.72	13.30	72.00	69.60	78.40	139.02	110.88	30.55	19.07	541.01
Runuff (m^3/s)		0.03	0.02	0.01	0.01	0.02	0.11	0.10	0.11	0.20	0.16	0.04	0.03	0.07
Runuff (m^3/s) (50%)		0.02	0.01	0.00	0.00	0.01	0.05	0.05	0.06	0.10	0.08	0.02	0.01	0.03
De masala (región 8)	27.38													
Precipitation (mm)		18.70	16.70	24.70	77.70	207.50	367.00	238.50	305.50	342.00	210.50	62.00	25.50	1896.30
Factors of P-R.		1.33	1.05	0.29	0.10	0.08	0.24	0.28	0.27	0.32	0.42	0.47	0.90	0.28
Runuff (mm)		24.87	17.54	7.16	7.77	16.60	88.08	66.78	82.49	109.44	88.41	29.14	22.95	530.96
Runuff (m^3/s)		0.25	0.20	0.07	0.08	0.17	0.93	0.68	0.84	1.16	0.90	0.31	0.23	0.49
Santa Inés (región 8)	29.18													
Precipitation (mm)		24.00	20.20	26.00	75.80	218.00	372.00	242.00	330.00	347.70	224.00	75.50	35.80	1991.00
Factors of P-R.		1.33	1.05	0.29	0.10	0.08	0.24	0.28	0.27	0.32	0.42	0.47	0.90	0.28
Runuff (mm)		31.92	21.21	7.54	7.58	17.44	89.28	67.76	89.10	111.26	94.08	35.49	32.22	557.48
Runuff (m^3/s)		0.35	0.26	0.08	0.09	0.19	1.01	0.74	0.97	1.25	1.02	0.40	0.35	0.56
La Quebradona 2 (región 8)	54.39													
Precipitation (mm)		16.50	13.50	23.80	74.50	215.00	370.00	244.00	332.00	350.00	233.50	64.50	23.50	1960.80
Factors of P-R.		1.33	1.05	0.29	0.10	0.08	0.24	0.28	0.27	0.32	0.42	0.47	0.90	0.28
Runuff (mm)		21.95	14.18	6.90	7.45	17.20	88.80	68.32	89.64	112.00	98.07	30.32	21.15	549.02
Runuff (m^3/s)		0.45	0.32	0.14	0.16	0.35	1.86	1.39	1.82	2.35	1.99	0.64	0.43	0.99
La Quebradona 1 (región 6)	20.61													
Precipitation (mm)		13.00	11.70	24.70	75.70	219.50	392.00	251.50	340.00	362.00	232.70	57.00	17.50	1997.30
Factors of P-R.		1.11	1.15	0.18	0.06	0.07	0.20	0.30	0.28	0.42	0.63	0.65	1.23	0.31
Runuff (mm)		14.43	13.46	4.45	4.54	15.37	78.40	75.45	95.20	152.04	146.60	37.05	21.53	619.16
Runuff (m^3/s)		0.11	0.11	0.03	0.04	0.12	0.62	0.58	0.73	1.21	1.13	0.29	0.17	0.43

Table 3

HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A

MEAN FLOWS CALCULATED BY METHOD OF RELATION "PRECIPITATION - RUNUFF" IN THE DAM POINT

name of basins	number of point in plane 2	Elevation (mols)	Area (Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Method of calculation
Citalá	1	701.63	914	4.17	2.64	2.01	1.94	4.00	30.25	48.52	51.69	67.25	48.06	20.55	8.21	24.11	HBV
Nunuapa			112.15	1.05	0.45	0.18	0.18	0.64	3.55	3.29	3.78	7.45	5.38	1.18	0.44	2.30	P-R
Demasala			27.38	0.25	0.20	0.07	0.08	0.17	0.93	0.68	0.84	1.16	0.90	0.31	0.23	0.49	P-R
Santa Ines			29.18	0.35	0.26	0.08	0.09	0.19	1.01	0.74	0.97	1.25	1.02	0.40	0.35	0.56	P-R
La Quebradona 1			20.61	0.11	0.11	0.03	0.04	0.12	0.62	0.58	0.73	1.21	1.13	0.29	0.17	0.43	P-R
La Quebradona 2 (47 %)			54.39	0.45	0.32	0.14	0.16	0.35	1.86	1.39	1.82	2.35	1.99	0.64	0.43	0.99	P-R
Zupuapa			40.02	0.14	0.18	0.06	0.07	0.24	1.22	1.22	1.45	2.48	2.31	0.51	0.24	0.84	P-R
Detiano (50%)			3.78	0.02	0.01	0.00	0.00	0.01	0.05	0.05	0.06	0.10	0.08	0.02	0.01	0.03	P-R
Mean flows at Dam Poin Project El Cimarron	Dam Zone		1201.51	6.54	4.17	2.59	2.55	5.71	39.49	56.47	61.34	83.25	60.88	23.90	10.08	29.75	

Note: Determination of flows* = **Equations of Regionalization (ERG)**
Relation "Precipitation-Runoff" (P-R)
Hydrological Modeling: HBV

Similarly, in the present study, for the purpose of comparison and validation, the calculation of the series of mean monthly flows at the Dam Point was carried, by means of the simulation of mean flows with the application of the HBV hydrological model, and by means of equations of regionalization. The results obtained are presented in Table 4, verifying that with the application of the HBV model an annual mean flow of 31.61m3/s and with the regionalization equations, an annual mean flow of 31.95m3/s

Table 4

HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A

MEAN FLOWS CALCULATED BY TRHEE METHODOLOGIES IN THE DAM ZONE

METHOD OF CALCULATION OF MEAN FLOWS	Area (Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Method of calculation
Mean flows determinated on the basis of hydrological model HBV	914	5.47	3.46	2.63	2.55	5.25	39.67	63.61	67.78	88.17	63.02	26.94	10.76	31.61	HBV
Mean flows calculated by relation "Precipition-Runuff" in the dam point	914	6.54	4.17	2.59	2.55	5.71	39.49	56.47	61.34	83.25	60.88	23.90	10.08	29.75	P-R
Mean flows calculated by means of Equation of Regionalization	914	5.11	3.41	2.72	2.88	7.08	44.97	60.82	66.30	92.00	64.59	23.90	9.61	31.95	ERG

Note: Determination of flows* = Equations of Regionalization (ERG)
Relation "Precipitation-Runoff" (P-R)
Hydrological Modeling: HBV

Graph 4 presents the comparative behaviour of the result of the mean monthly flows for the Dam Point which were obtained using the three methodologies. However, in the final analysis the results obtained by means of precipitatio-runoff were established as the characteristic flows, given that they define the most conservative estimate of inflows to the reservoir, on the basis of which the environmental flows will be determined.

Graf. 4

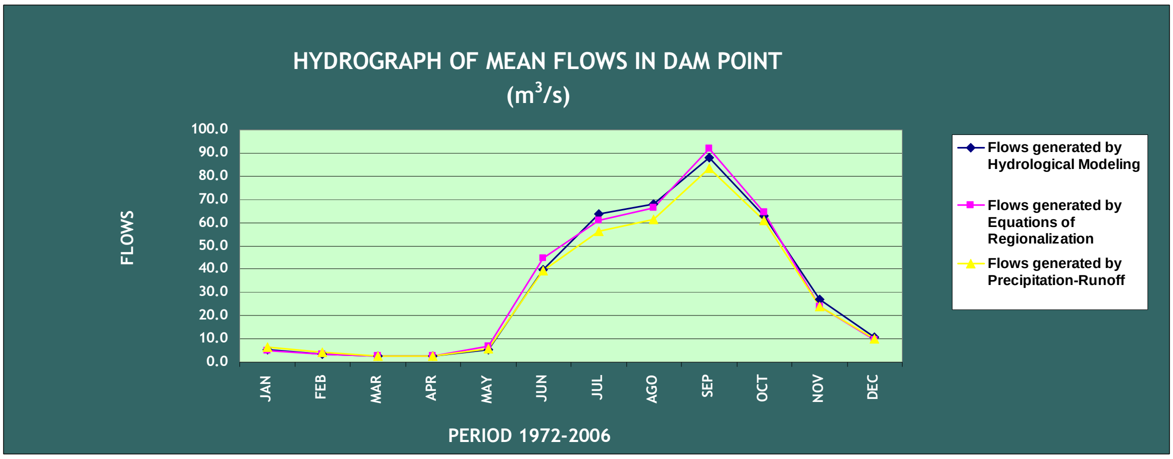


Table 5 presents the results obtained in the determination of environmental flows at the Dam Point, by means of methods of hydrological indices, which are compared with the actual mean flows. In the first scenario, the variable environmental flows for the dry season (November-April) were determined as being 35% of the mean flows for the dry season; while the ambient flows for the rainy season (May-October) were determined as being a percentage between 34%-60% of the mean flow calculated for the same period of the rainy season. The other scenario of environmental flows, was that defined initially in the factability study previous to this, in which an environmental flow of 3.0 m^3/s was established.

Table 5

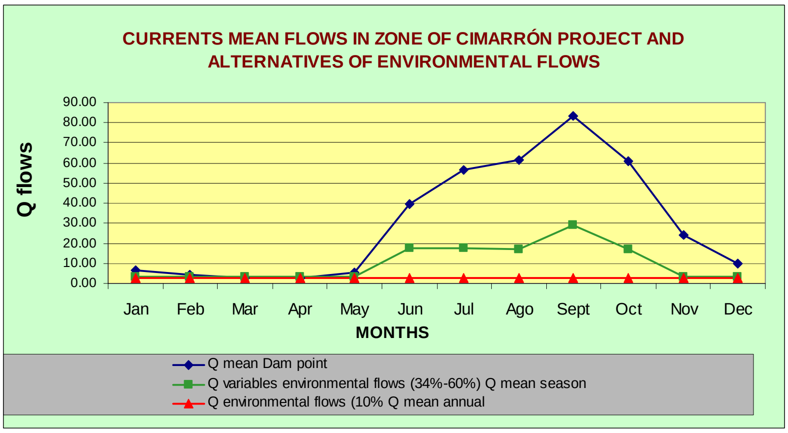
HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A

SYSTEM OF MEAN CURRENT FLOWS (Qm) AND SCENE OF POSSIBLE ENVIRONMENTAL FLOWS PROJECTED IN DAM ZONE (Q env)

Flows	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Metodología de Cálculo
Mean Flows in Dam Zone	6.54	4.17	2.59	2.55	5.71	39.49	56.47	61.34	83.25	60.88	23.90	10.08	29.75	P-R
Variables Environmental Flows	3.07	3.04	3.05	3.06	3.03	17.38	17.51	17.18	29.14	17.05	3.11	3.02	9.97	Hydrological Indexes
Environmental flows as (10% Qmed anual)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	10% Qm annual

Graf. 5

Graph 5 illustrates comparatively the regimen of actual monthly flows in comparision with the establishment of whichever of the two scenarios in the operation the El Cimarrón Hydroelectric Project



Starting from the Dam Point the mean monthly flows were determined for each of the points of interest, taking into account the contributions arising from the various sub-basins which flow into the River Lempa. This analysis was carried out by means of Equations of Regionalization and Relations of Precipitation-Runoff. In addition, the mean flows were taken into account, as established by the historical measurements at the Zapotillo and Paso del Oso hydrometric stations, which are located at points 4 and 5 of Map 2. In table 6 the results of the calculations of the mean flows in *(mt^3/seg)* obtained as far as the point of the plant for the captation of potable water for San Salvador is presented, as indicated at point 6 of Map 2.

Table 6

HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A

HYDROLOGICAL BEHAVIOR OF THE LEMPA RIVER ON THE BASIS OF CALCULATED AND REGISTERED FLOWS

WITH OPERATION OF THE HIDROELECTRIC DAM "GUAJOYO"

EL SALVADOR, C.A

Basins and points of confluence with lempa river	Point in Map 2	Method of calculation	Zonification	Range of Area (Km^2)	Elevation (mols)	Area (Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sept	Octub	Nov	Dec	Annual
Mean flows in dam point						1201.51	6.54	4.17	2.59	2.55	5.71	39.49	56.47	61.34	83.25	60.88	23.90	10.08	29.75
Mean flows in dam point	2				505	1201.51	6.54	4.17	2.59	2.55	5.71	39.49	56.47	61.34	83.25	60.88	23.90	10.08	29.75
Tahuilapa - El Rosario		CRH	------	-----		137.58	0.38	0.24	0.28	0.36	1.61	4.81	4.71	4.60	8.38	5.44	1.19	0.60	2.72
La Quebradona 2 (53 %)		ERG	4	25 - 587		61.35	0.15	0.15	0.14	0.16	0.45	2.28	2.04	2.38	3.58	2.54	0.45	0.23	1.14
La Quebradona 3 (60%)		PR	6	-----		48.8	0.17	0.16	0.06	0.09	0.26	1.25	1.35	1.63	2.53	2.72	0.51	0.29	0.92
El Coyolito		PR	8	-----		16.98	0.06	0.03	0.02	0.04	0.08	0.46	0.40	0.46	0.56	0.46	0.08	0.04	0.22
Mean Flows before confluence of Desague River	3				335	1466.22	7.30	4.74	3.09	3.20	8.12	48.29	62.93	70.41	98.30	72.03	26.14	11.24	34.65
Mean Flows before confluence of Desague River						1466.22	7.30	4.74	3.09	3.20	8.12	48.29	62.93	70.41	98.30	72.03	26.14	11.24	34.65
Desague River		CRH	------	------		2788	21.23	22.91	23.77	18.98	12.82	17.94	17.06	16.14	27.39	30.92	21.42	21.98	21.05
Station Zapotillo	4				328	4254.22	28.53	27.65	26.86	22.18	20.94	66.23	79.99	86.55	125.69	102.96	47.56	33.22	55.70
Station Zapotillo					328.78		26.68	26.38	23.38	21.50	18.48	41.22	54.49	60.20	101.61	117.80	40.03	35.43	47.27
Zapotillo zone						4254	28.53	27.65	26.86	22.18	20.94	66.23	79.99	86.55	125.69	102.96	47.56	33.22	55.70
Texis o Ipayo		ERG	6	35 - 845		190.82	1.56	1.48	1.42	1.51	2.11	3.88	4.77	5.40	6.87	4.83	2.20	1.70	3.14
La Quebradona 3 (40%)		PR	6	------		32.53	0.09	0.06	0.03	0.05	0.15	0.76	0.87	0.96	1.46	1.55	0.24	0.18	0.53
Peñanalapa		ERG	5	45 - 185		46.74	0.12	0.09	0.09	0.13	0.44	2.06	1.67	2.00	3.56	2.31	0.49	0.18	1.10
Honduritas		PR	6	------		6.6	0.02	0.01	0.01	0.01	0.03	0.15	0.19	0.19	0.29	0.32	0.05	0.03	0.11
Total Zona Paso del Oso							30.31	29.29	28.41	23.88	23.67	73.08	87.49	95.10	137.87	111.97	50.55	35.31	60.58
Station Paso del Oso	5	CRH			294.6	4531.4	36.31	31.34	27.56	24.73	25.86	77.85	81.19	83.58	126.34	109.93	48.79	43.47	59.75
						4530.69													
Station Paso del Oso		ERG	------	-----	294.6	4531.4	36.31	31.34	27.56	24.73	25.86	77.85	81.19	83.58	126.34	109.93	48.79	43.47	59.75
Barranca Honda		PR	8	-----		25.78	0.05	0.02	0.02	0.05	0.12	0.70	0.68	0.68	0.83	0.74	0.11	0.10	0.34
El Tular		ERG	5	45 - 185		54.25	0.15	0.11	0.10	0.15	0.53	2.48	2.01	2.41	4.29	2.78	0.59	0.22	1.32
Pepesca		PR	8	-----		9.74	0.02	0.01	0.01	0.02	0.05	0.26	0.26	0.26	0.32	0.28	0.05	0.03	0.13
El Pital		PR	9	-----		9.13	0.05	0.03	0.05	0.09	0.10	0.17	0.17	0.19	0.27	0.28	0.08	0.08	0.13
San Isidro		PR	9	-----		17.23	0.10	0.06	0.10	0.18	0.19	0.33	0.32	0.38	0.51	0.56	0.15	0.16	0.25
Las Pavas		PR	9	-----		17.57	0.10	0.07	0.11	0.20	0.20	0.34	0.33	0.40	0.53	0.59	0.16	0.11	0.26
Quebrada Honda		PR	6	-----		13.54	0.02	0.01	0.01	0.03	0.07	0.31	0.38	0.43	0.61	0.72	0.10	0.04	0.23
Mojaflores		ERG	------	-----		47.8	0.10	0.06	0.06	0.09	0.25	1.40	1.00	1.15	1.69	0.99	0.24	0.12	0.60
Captation of Water for San Salvador	6				276	4726.44	36.89	31.71	28.05	25.54	27.37	83.84	86.35	89.48	135.40	116.88	50.27	44.34	63.01

Note: Determination of flows* = Equations of Regionalization (ERG)
Relation "Precipitation-Runoff" (P-R)
Hydrological Modeling: HBV
Historicals records : CRH

Table 7 presents the results of the mean flows obtained at the point of the plant for the captation of potable water for San Salvador for the actual conditions of the hours when the El Guajoyo Hydro electrical plant is in operation and for the hours of the day when it is not operating.

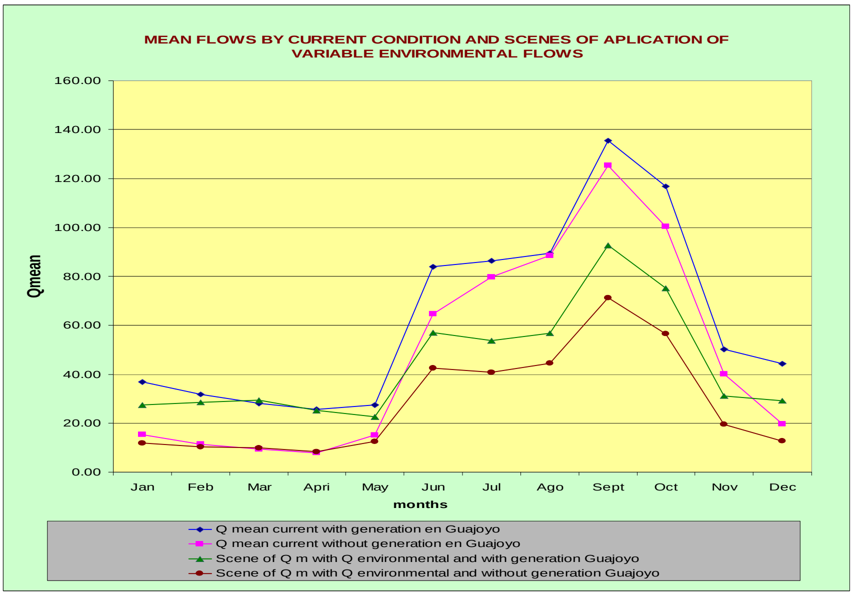
On the other hand it presents the scenario for the mean flows at the same point, for the conditions of the presence of variables environmental flows with and without the operation of the Guajoyo Hydroelectric Dam.

Table 7

CURRENT MEAN FLOWS (Qm) AND PROJECTED MEAN FLOWS AT THE ZONE OF CAPTATION FOR THE POTABLE WATER SUPPLY FOR SAN SALVADOR
HYDROELECTRIC DAM "EL CIMARRON" EL SALVADOR, C.A
EL SALVADOR C.A.

MEAN FLOWS AT THE ZONE	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Method of calculation
Q mean current with generation en Guajoyo	36.89	31.71	28.05	25.54	27.37	83.84	86.35	89.48	135.40	116.88	50.27	44.34	63.01	ERG-PR
Q mean current without generation en Guajoyo	15.36	11.36	9.42	7.90	15.16	64.63	79.79	88.57	125.34	100.39	40.20	19.80	48.16	ERG-PR
Scene of Q m with Q environmental and with generation Guajoyo	27.43	28.54	29.36	25.19	22.49	56.96	53.69	56.84	92.82	75.08	31.23	29.13	44.06	ERG-PR
Scene of Q m with Q environmental and without generation Guajoyo	11.90	10.23	9.88	8.41	12.47	42.52	40.82	44.40	71.23	56.56	19.41	12.75	28.38	ERG-PR

Grafica 6



. In Graph 6 the differing regimens for mean flows at the point of captation for the potable water supply for San Salvador is presented, in accordance with the actually existing conditions and with the two situations that are presented in the presence of ambient flows.

Finally, an analysis is made of the disposable potential and energy which the El Cimarrón Hydroelectric Project could produce per annum, given the necessity to maintain or preserve in the hydric system a regimen of variable environmental flows such as have been established. For this purpose, primarily, in Table 8 the correlation between the volume of the reservoir in mt3 and the respective levels in msnm. The same was carried out on the basis of the curve of area/volume/elevation of the functioning of the reservoir, developed in the project´s factibility study

Table 8

Correlation of Elevations and Capacities of Dam in the Hidroelectric Project "El Cimarrón" El Salvador C.A
(Elaborated on basis of Curve elevation/area/capacity of reservoir)

Elevation (msnm)	Relative Volume (mt^3)	Accumulated Volume (mt3)
700		720,000,000
	160,000,000	
690		560,000,000
	140,000,000	
680		420,000,000
	80,000,000	
670		340,000,000
	80,000,000	
660		260,000,000
	60,000,000	
650		200,000,000
	50,000,000	
640		150,000,000
	50,000,000	
630		100,000,000
	15,000,000	
620		85,000,000
	15,000,000	
610		70,000,000
	12,000,000	
600		58,000,000
	12,000,000	
590		46,000,000
	12,000,000	
580		34,000,000
	12,000,000	
570		22,000,000
	12,000,000	
560		10,000,000
	10,000,000	
550		0

Table 9 presents a scenario for the establishment of the potential and annual energetic generation, on the basis of flows regulated for hydroelectric generation and the annual volumetric balance requirements of the reservoir. Thus, an annual potential in the order of 200Mw can be obtained, along with a generation of energy per annum of 560Gwh, with an operation of the generation of electricity estimated at 2808 hours per annum.

Table 9

HYDRIC-ENVIRONMENTAL EVALUATION OF HIDROELECTRIC DAM "EL CIMARRON"
EL SALVADOR, C.A
SCENARIO POR THE ESTABLISHMENT OF THE MEAN POTENTIAL AND ANNUAL ENERGETIC GENERATION ON THE BASIS OF THE ANNUAL OPERATION OF RESERVOIR

Months	Description	Mean inflows without Environmental flows and Mean outflows by generation (m^3/s)	Days	Storage Change (m^3)	Elevation of water table of reservoir (mols)	Estimated elevation of generation Plant (msnm)	Power (Mw)	Hours of Generation on the month	Energy (Gwh)
JANUARY	Qinflow	3.5	31	9,374,400					
	Qoutflow	35.0	8	24,192,000	694.0	305	112.19	192.00	21.54
	Storage change			-14,817,600					
	Initial volume			632,078,112					
	Final volume			617,260,512					
FEBRUARY	Qinflow	1.1	28	2,661,120					
	Qoutflow	40.0	6	20,736,000	693.0	305	127.89	144.00	18.42
	Storage change			-18,074,880					
	Initial volume			617,260,512					
	Final volume			599,185,632					
MARCH	Qinflow	0.0	31	0					
	Qoutflow	45.0	6	23,328,000	691.7	305	143.40	144.00	20.65
	Storage change			-23,328,000					
	Initial volume			599,185,632					
	Final volume			575,857,632					
APRIL	Qinflow	0.0	30	0					
	Qoutflow	42.0	8	29,030,400	690.0	305	133.25	192.00	25.58
	Storage change			-29,030,400					
	Initial volume			575,857,632					
	Final volume			546,827,232					
MAY	Qinflow	2.7	31	7,231,680					
	Qoutflow	52.0	8	35,942,400	688.0	305	164.12	192.00	31.51
	Storage change			-28,710,720					
	Initial volume			546,827,232					
	Final volume			518,116,512	Min Volume ending the rain season				
JUNE	Qinflow	22.1	30	57,309,120					
	Qoutflow	75.0	8	51,840,000	687.2	305	236.21	192.00	45.35
	Storage change			5,469,120					
	Initial volume			518,116,512					
	Final volume			523,585,632					
JULY	Qinflow	39.0	31	104,457,600					
	Qoutflow	82.0	8	56,678,400	689.1	305	259.54	192.00	49.83
	Storage change			47,779,200					
	Initial volume			523,585,632					
	Final volume			571,364,832					
AGOEST	Qinflow	44.1	31	118,117,440					
	Qoutflow	82.0	12	85,017,600	691.7	305	261.30	288.00	75.25
	Storage change			33,099,840					
	Initial volume			571,364,832					
	Final volume			604,464,672					
SEPTEMBER	Qinflow	54.2	30	140,382,720					
	Qoutflow	82.0	12	85,017,600	694.5	305	263.19	288.00	75.80
	Storage change			55,365,120					
	Initial volume			604,464,672					
	Final volume			659,829,792					
OCTUBER	Qinflow	43.8	31	117,394,272					
	Qoutflow	69.0	14	83,462,400	697.3	305	223.06	336.00	74.95
	Storage change			33,931,872					
	Initial volume			660,000,000	Max Volume starding the dry season				
	Final volume			693,931,872					
NOVEMBER	Qinflow	20.8	30	53,913,600					
	Qoutflow	68.0	15	88,128,000	697.3	305	219.82	360.00	79.14
	Storage change			-34,214,400					
	Initial volume			693,931,872					
	Final volume			659,717,472					
DECEMBER	Qinflow	7.1	31	19,016,640					
	Qoutflow	45.0	12	46,656,000	695.3	305	144.73	288.00	41.68
	Storage change			-27,639,360					
	Initial volume			659,717,472					
	Final volume			632,078,112					
							Annual Mean Capacity (Mw)	**Hours of annual generation (hr)**	**Annual Energy generated (Gwh)**
							199.32	**2808.00**	**559.70**

EVALUATION

The north-west zone of El Salvador, the area where it is intended to develop the El Cimarrón Hydroelectric Project is precisely the fraction of the territory of El Salvador where the greatest and optimum disposability of surface water in the entire Hydrographic Basin of that part of the River Lempa pertaining to El Salvador is concentrated, as much for its quantity as its quality; and whose indices favour a great potential for exploitation for the purposes of irrigation, human consumption by means of conventional methods of potablization, recreational use and environmental benefits.

In this way, the section constituted from the entry into the country of the fluvial channel at Citalá, to the zone for the diversion of water for the supply of potable water for San Salvador, which posseses a length of 81km, constitutes the section possessing the greatest adavantages for the integral and sustainable exploitation of the hydric resource as contemplated within a scenario of ordering and national planning. This section of the River Lempa is considered by the Ministry for the Environment and Natural Resources (MARN) to be the only fraction with an availability supply of "clean water" along the entire channel of the River Lempa, presenting values of DBO_5 of less than 4.0 mg/litre, which makes it apt for potabilibilization by means of conventional methods, as detailed by *Programme for the Monitoring of Surface Water*, realised by *the National Service for Territorial Studies (SNET) (April 2005)*, the investigative body ascribed by the MARN.
This situation is possible thanks fundamentally to the natural streams which enter the country at Citalá, before arriving at the confluence with the River Desague, and which present a high level of conservation in so far as quality is concerned, due to the considerable presence of mountainous regions and the reduced urban and industrial development. However, the streams which enter from Guatemala and which are regulated through the operation of Guajoyo Hydroelectric Dam do present a significant level of contamination, principally at certain times of year, due to the fluvial flows which are mixed with serviced waters and residues from important populated areas in Guatemala and agricultural zones with the intensive use of agro-chemicals and fertilisers which flow into Lake Guija. On the other hand, this low quality is seen to be potenciated by the effects of recurrent eutrofization in said lake, which serves as the reservoir for the operation of the Guajoyo Hydroelectri Centre.
With this in mind, it is possible to understand the importance of preserving and maintaining the flows stemming from "Citalá" which have an essential function of dilution, making possible the diminution of the contaminating charge of the flows which enter at Guajoyo.
Subsequently, these flows are integrally exploited downriver, for cultivation by means of extensive belts of irrigation, and principally for the supply of potable water to large areas of San Salvador.
In this way, the River Lempa acquires a special importance due to its essential contribution as a strategic source of superficial and subterranean hydric resources, and as a territorial ambit which is essential for the preservation of biodiversity, of the fluvial and riverside ecosystems, and of the local flora and fauna.
Nevertheless, we are dealing with a hydrographic territory with a high level of environmental fragility due to exogenous factors, such as the incidence of hydroclimactic aspects, and endogenous factors which are manifested by an accelerated process of deforestation, a gradual increase in the indices of contamination, inadequate soil use, loss of woodland areas, and a high level of erosion and sediment loss which results in the loss of fertile land and a progressive hydromorpho-lithological disequilibrium of the river.
Added to this, the principals rivers which make up the hydrographic basin of the River Lempa, and others of great importance to the country, have, in recent decades, suffered the impact of a gradual historical decrease in flows during the summer, which is attributed to the interphase of various exogenous and endogenous aspects, as appears in the study of the behaviours of flows in summer, developed by SNET (2002).
The calculation of environmental flows, solely by means of methods of hydrological indices, such as has been done in the present study, is insufficient to describe and integrate all the variables in the correlation of the hydrodynamic aspects of the river, with the essential aspects necessary for the preservation of the fluvial habitats, the modulation of the flood plains (which is indispensable for terrestrial and aquatic biodiversity), and the preservation of woodland areas and river canopies, which are sustained by the river and it's periodic flux.
It is important to emphasise that the river species depend on the natural system of flows, that is say, of the low and high flows, their periodicity and distribution over time and space, as does the conservation of the

sediment dynamic and the geomorphological structure of the river. These aspects have never been studied for the River Lempa, which makes it complicated, and beyond the scope of this study, to correlate them with the fluvial and riverside habitat and the surrounding environment. The variability and periodicity of the flows is something that should integrated in the study of the environmental flows, in which the changes in the systems of flow are directly interacting with the ecosystem, to the extent that both elements make up, a single hydro-ecological system of environmental sustainability.

CONCLUSIONS

1. The implementation of the hydroelectric project will have a direct effect on the principal source of drinking water for the metropolitan area of the capital city, San Salvador, which is taken directly from the River Lempa whose channel will be interrupted by the implementation of the hydroelectric project 81km upstream of the catchment point. This would bring about a reduction in the order of 35% of the mean flows presently attained in winter. During the summer months, one could expect a reduction in the range of 25%-37% with the exception of the months of March and April where one could expect a pattern of flows similar or even marginally superior to that pertaining at present, reaching flows in the order of 3.0m^3/s.The implementation of the variables environmental flows would bring about a decrease in the dilution of the flows coming from Guajoyo in which the flows coming from Citalá carry out an essential function. This could increase the cost of treatment and purification of the water supply which is currently established as being in the order of 2.6m^3 /s for the supply to San Salvador, but which, in accordance with official projections it is intended to increase in the medium term. Although there exist other sources of water supply for the capital, which has a population of 2.3 million, making up 28% of the population of the country, the catchment from the River Lempa represents one of the most accesible supplies with an installed capacity of 4.8m^3/s. The River Lempa therefore constitutes a fundamental source which must be maintained and preserved.

2. The determination of environmental flows by means of hydrological indices, as the basic reference for the environmental preservation of the aquatic and riverside ecosystems and, fundamentally, for the preservation of the hydric availability, establishes values in the range of 3.05m^3/s and 29.00m^3/s which will not permit the predicted generation of electricity of approximately 680 Gwh, on the basis of capacity 242Mw, in particular during the 6 months which make up the dry season. This can be seen in the typical scenario for the regulation of the reservoir, given the preservation of the environmental flows, which determines a potency in the order of 200Mw which would supply a estimated 560Gwh to the national grid, equivalent to 10.5% of the annual demand in El Salvador.

3. From an Hydrico-Environmental point the implementation of the El Cimarrón Hydroelectric Project, given that it would have a severe impact on the fluvial dynamic of the river, and on the hydric availability for the various primary uses. The impact on the fluvial system would generate a des-equilibrium and would directly alter the local and surrounding fluvial ecosystems, along with the preservation of the riverside areas. There would also be an adverse affect on the way of life of the riverside communities whose interaction with the River Lempa constitutes the natural ambit in which they have evolved over the centuries their productive, social, economic and cultural activities. Finally, it would, in the last analysis imply an irreversible alteration in the conformation of the tourist industry in the north of the country and on the ecosystem of which the River Lempa is an essential element.

4. The El Cimarrón Hydroelectric Project is planned for an area which is already suffering a profound hydrico-environmental crisis, which has been warned about in various studies which have been carried out by various public and private bodies. This situation has its roots in climactic and endogenous factors. Official studies have determined that there presently exists a gradual diminution in the river flows during the summer, pointing out that many of these could convert in the short or medium term in mere winter gullies. In addition there has been a lack of foresight, legislation, regulation and planning at a national level, which has permitted a type of socio-economic development which has led to environmental deterioration and to sceptism in the face of the gravity of the problem. This has contributed to the fact that the processes of deforestation, contamination of rivers, loss of fertile soil due to erosion, an incompatible urbanisation in green belts, and the gradual loss of woodland area brought about by an extension of agricultural activity, all contribute significantly to the deepening of the hydrico-environmental problem in which the El Cimarrón Hydroelectric Project will be inserted.

REFERENCES

SNET (2005), Methodology Equations of Regionalization and Relations Precipitation – Runoff
COYNE ET BELLIER (2005), Feasibility Study, phase 1; Hydroelectric Dam Project “El Cimarron”
Seumas O braonain, Translator.