

# Hydropower Optimization: Study of the System of the Rivers Las

# Cañas-Gastona-Medina

Santiago Reyna<sup>1</sup>, Teresa Reyna<sup>1</sup>, Fabián Fulginiti<sup>1</sup>, María Lábaque<sup>1</sup>, J. Lande<sup>2</sup>. (1. Faculty of Exact, Physical and Natural Sciences, National University of Cordoba, Argentina; 2. Lande y Asociados, Piedras 77, Buenos Aires, 1070, Argentina)

**Abstract:** Hydroelectric power generation offers significant advantages in terms of total costs and stands today as an environmentally sustainable alternative. The current development of several hydroelectric projects in Argentina shows that there is a high potential for the development of renewable energy sources, with major environmental advantages over other ways of generating energy. The renewable nature of these sources contrasts with the finite nature of domestic fossil resources. In this context, hydropower is a mature, accessible and efficient option to meet the growing demand for energy services in the country. Optimization applied to hydroelectric designs allows for adequate solutions for each power system. This article presents hydropower optimization for the Multi-purpose River System of Las Cañas, Gastona and Medina.

Key words: hydroelectricity; Potrero del Clavillo; Tucumán; Catamarca; hydraulic power; hydroelectric optimization; sustainable

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# **1. Introduction**

The energy crisis of 1973 and 1979, caused by the sharp rise in oil prices, led to the exploitation of inexhaustible renewable resources, as opposed to fossil resources, limited in space and time (ESHA, 1998). Later, the pessimistic predictions about the depletion of fossil resources, the general concern for the phenomenon of global warming, and the uncertainties about the future of nuclear waste, again highlighted the advantages of generating electricity from renewable resources. Recently, in March this year, the European Union submitted a formal pledge to the United Nations stating how much it is willing to reduce greenhouse gas emissions ahead of climate change talks in Paris later in the year. According to the meeting of environment ministers, the EU will be targeting to reduce its emissions by at least 40 percent by 2030 as compared with levels recorded in 1990. Pope Francis encyclical letter ("Laudato Si", May 2015) states the necessity to work to stop global climate changes.

Santiago Reyna, Ph.D., Faculty of Exact, Physical and Natural Sciences, National University of Cordoba; research areas/interests: sustainable development, hydropower energy. E-mail: santiagoreyna@gmail.com

Teresa Reyna, Ph.D., Faculty of Exact, Physical and Natural Sciences, National University of Cordoba; research areas/interests: sustainable development, hydropower energy, research and innovation. E-mail: teresamaria.reyna@gmail.com

Fabián Fulginiti, Mag., Faculty of Exact, Physical and Natural Sciences, National University of Cordoba; research areas/interests: hydropower energy. E-mail: fabianfulginiti@gmail.com

Maria Labaque, Mag., Faculty of Exact, Physical and Natural Sciences, National University of Cordoba; research areas/interests: hydropower energy, research and innovation. E-mail: mlabaque@gmail.com

Jaime Lande, Eng., Jaime Lande y Asociados, research areas/interests: hydropower energy. E-mail: jlande@jlande.com.ar.

Hydroelectric power generation is an interesting option that will need to develop faster if this target wants to be reached.

#### **1.1 Environmental Considerations**

Hydropower offers significant advantages over other energy sources; among them we can emphasize: mature technology; available in Argentina (and other Latin American countries); "does not pollute" or "pollutes less"; produces energy at ambience temperature; allows recreation; prevents flooding by regulating the flow; source is not exhausted; experience and technology is accessible for developing countries. However, considering the fact that the environmental impacts caused by hydropower vary significantly according to the location of exploitation and the technological solution chosen, good care has to be taken to select the best solution in environmental terms.

From the point of view of location, exploitation in a mountain generates different impacts from the ones generated in a plain. From the technological point of view, exploitation with regulating reservoir generates impacts that are quantitatively and qualitatively different from those generated by exploitation of flowing water, within which one might even distinguish, for these purposes, between those that divert water and those that do not (ESHA, 2006).

#### **1.2 Physical Characteristics of the Region**

The area implantation of the works is located in the basin of River Medina and covers the territory of the Argentine provinces of Tucuman and Catamarca. It is located in the upper portion of River Medina, geographically called "Las Estancias" and in particular, in the area called "Campo del Pucará". Figure 1 shows the location of the area of analysis at a regional level.



Figure 1 Geographic Location of the Area of Rivers Las Cañas-Gastona-Medina System

The general hydrographic network lies in the Eastern slope of "Nevados del Aconquija" (Aconquija Peaks), between 4500-5000 m heights and a 500 masl contour. The region is characterized by the existence of localized

areas where rainfall exceeds 2,000 mm per year, coinciding with approximately 1,500 to 2,000 meters asl (Figure 2). Weather conditions in the basin are characterized by marked thermal and rainfall gradients throughout its extended area.



Figure 2 Some Pictures from Creeks into the Basin in the Cochuna River

The basin is exposed to significant erosion processes, mainly in the area below 2,500 masl, since above this area, geological formations are more stable; however, weathering processes located on the upper slopes are very active, too.

The complex System of Rivers Las Cañas-Gastona-Medina is a multipurpose project with the following order of priority for its different uses:

- (1) Regularized and seasonal hydropower generation (with possibility of peak production),
- (2) Flood protection,
- (3) Supply of drinking water to several towns, for industry and irrigation and,
- (4) Tourism and recreation.

However, the main objective of this venture is hydroelectric generation (that pays for the project) which is based on harnessing the seasonal river flows of River Las Cañas and after a diversion work, water from the main tributaries of River Cochuna (Figure 3). Both rivers have abundant flows during the summer and they have large topographic slopes. Mean flow rates are relatively modest but level changes are important.



Figure 3 Hydrography

For the alternative under consideration, the total difference in height between the top catchment area in river La Laguna at 1,670 masl and the delivery at Plant No. 2 in River Las Cañas at 785 masl represents a total potential difference in height of 885 m for the intervention.

Intake for the diversion will be conducted in the upper basin of River Cochuna by means of grid diversion dams with their respective sand sedimentators. In the alternative considered, sequential, catchments will use River La Laguna, Bolsón Creek, Casa de Piedra Creek, Vallecito Creek, Esquina Grande Creek and La Quinta Creek.

The water will be piped through tunnels which should ensure a minimum slope carrying capacity equal to or greater than the maximum design capacity of the system at that point. Most of the tunnels will be excavated in rock.

Power Plant N° 1 will be located above the maximum level of the reservoir planned in the area called Potrero del Clavillo. This dam will be located in the same position as the old project of Water and Power Agency (Agua y Energía) of the 70s.

## 2. Hydroenergy Optimization

The optimization of the power plants of the Multipurpose Water Complex of Rivers Las Cañas–Gastona–Medina was carried out under a continuous simulation scheme, using flow values registered at the site of implantation of the reservoir and with simulated values for the contribution of the water flows to be diverted. An optimal operation proposal was obtained, which complies with the rules and restrictions, maximizing the generation for each of the simulated hydrological years which, in this case, correspond to the time series.

The objective was to maximize the revenues associated with the sale of electricity production of the plants, meeting the requirements of flow rates and volumes associated with environmental restrictions.

The model allowed incorporating the adaptations to the two presented variants of hydraulic machines and conduits, in addition to the restrictions set forth above.

#### 3. Methodology

In systems of hydroelectric power generation, optimal operation of the system is conceived as a complex optimization problem on a large scale, considered as taking decisions regarding water discharge or turbinated flow for hydroelectric generation over a given horizon of time.

In order to make the model, it is necessary to carry out the statistical, hydrologic and hydraulic studies first to determine the number of inputs to reservoirs, features of dams and plants, and the turbomachinery to be used. With respect to the data on flows for the model, we worked with the existing stations Potrero del Clavillo and Los Hornitos. The gauging station Potrero del Clavillo is located on Rio Las Cañas and combines the flows from its tributaries (Rivers Las Chacras, Potrero and del Campo). Table 1 shows the location of the main stations and their main information.

For sizing the reservoir, hydrological, topographical and geological studies related to the location of the dam and future reservoir are required. Previous studies to define whether or not to artificially regulate a river usually refer to the different needs that the dam to be executed will have. In this case, as it is a multipurpose exploitation system, besides power generation, it was necessary to consider flood control and other applications due to the economic and social consequences they produce. The flows of Potrero del Clavillo station were used for hydropower optimization. Daily mean Q series recorded by EVARSA (in charge of keeping the hydrological series) was completed, unifying the information with the data obtained from the SSRH (National Subsecretary of Water Resources) through the program "National System of Water Information". The information dates back to 58 years ago (02/20/1953 to 08/31/2011). Figure 4 presents the graph of the daily flow record in Potrero del Clavillo station with their characteristic values.

The module obtained for the series of mean daily flows unified for Potrero del Clavillo is  $3.65 \text{ m}^3/\text{s}$ .

To assess the generation of different alternatives preliminarily, duration flow curves were determined at each analysis point.

In subsequent instances, specific watershed degradation was estimated by using different methodologies in order to consider them when defining the useful volume of the reservoir and its maintenance mechanisms.

In Figure 5, the flow diversion works to Potrero del Clavillo reservoir are presented.

Within the flow diversion works, we can find the compensation reservoir located in the basin of river Las Cañas, that allows leading the overflow derived (and not turbinate) directly through creek La Quinta up to Potrero del Clavillo reservoir.

Catchment points for driving flows considered in this alternative analyzed, have the following heights:

- La Laguna River (Cota 1670 msnm)
- El Bolsón River (Cota 1663 msnm)
- Vallecito River (Cota 1655 msnm)
- Compensation Reservoir on creek La Quinta (1611 msnm)

From River La Laguna and until reaching the compensation reservoir, piping will have a diameter of 1400mm. The flows captured in River Vallecito will be carried independently using a parallel pipe of 1400 mm of diameter to avoid increasing the previous conducting pipe, while decreasing the system vulnerability and therefore enabling maintenance in either pipeline.

A hydrological rainfall-runoff transformation model was generated, using HEC-HMS software (U.S. Army Corps of Engineers, 2010), which was calibrated in its runoff parameters by using existing records. Using this model, hydrographs associated with extreme recurrences were determined for the design of the diversion works and the main reservoir.

## 4. Hydropower Optimization Model

After collecting and systematizing hydrometeorological information that allows assessing water availability, it is necessary to determine the variables that define the hydropower generation system. The main objective is to optimize the use of water resources, attending to the technical and economic constraints and by being efficient to sell in the interconnected market.

River	Station	Latitude	Longitude	Sup (km²)	Height (m.s.n.m.)	Period	Agency
Cochuna	Los Hornitos	27° 20′	65° 55′	155	1000	1953-80 1981-84	Agua y Energía D.P.A.
Cañas	Potrero del Clavillo	27° 24´	65° 59′	1000	1300	1963-2010	Agua y Energía EVARSA
Cañas	Las Hachas	27° 21′	65° 51′	1100	600	1949-50 1953-69	Agua y Energía EVARSA

Table 1 Stations



Figure 4 Serie Flows of Estación Potrero del Clavillo



Figure 5 Location of Flows Bypass the Dam Contribution to Potrero del Clavillo

The analyzes carried out are related to the design instance of the project, which are required to define and clarify a multiplicity of elements (location of sites for the diversions, volume of reservoirs, capacity of power plants, operation rules ...) what entails a degree of complexity that makes it difficult to obtain results that can be compared between each other. Consequently, we find a multivariable system, which requires setting the value of some of these variables, whose effect is considered to be less influential and, "a posteriori", incorporate them in the analysis.

On the other hand, the optimal operation of the system is conceived as a complex problem of dynamic stochastic optimization, on a large scale, raised as decision making regarding the discharges of water or turbinated flows for hydroelectric generation during a given horizon time.

The employed optimization scheme uses the simulation model sequentially setting the variables mentioned as seen in Figure 6.

The simulation model itself considers the multiplicity of variables enunciated allowing setting their values

for each simulation. Certain restrictions of time and space water balance, together with technical restrictions such as water storage capacity in the reservoirs, must be observed. For this reason, a resolution scheme (Figure 7), whose time lapse allows simulating base and peak generation, was generated, considering the variables presented in Figure 6.

Through the scheme of resolution proposed, a spreadsheet in MS-Excel that automatically calculates each variable for time i based on the values of time i-1 using the exposed relationships (Figure 6) was developed. All flows were converted to volumes, corresponding to their respective time passage.

The application of scheme of resolution proposed in each instance of the optimization process (Figure 5) allowed determining each variable or feasibility range to bound decision making. As an example, Figure 8 shows the simulation of the annual energy generated by the system and the turbined flows against the variation in the flow capacity of Central N°2 (4th Round of Simulations in Figure 6).



Figure 6 Scheme of Process Optimization



Figure 7 Scheme of Calculation and Variables Considered



Figure 8 Scheme of Process Optimization

The technical efficiency of the generating units for the calculation of the power generated was estimated from homologous stations. Once defined, the equipment supplier should be requested to provide charts for the turbines, commonly known as "hilly diagrams" (technical efficiency based on net height and discharge water) and set preliminary calculations. In Figure 9, it can be seen one of the operation curves used for a group of turbines in a variant.



Figure 9 Performance Curve for Group of Turbines

Similarly, the height vs. volume curves estimated for each reservoir site, should be appropriately adjusted.

## 5. Results

Results were obtained for each of the alternatives: the dimensions (heights and volumes) of the reservoirs, the mean power production per plant, and revenues from sale of energy and from power available. The results supported the choice of Pelton machines for the compensating reservoir (Plant 1) and Potrero del Clavillo (Plant 2).

	Mean of Diverted Flow	Design Flow per Turbine	Number of Turbines	Maximum Turbinated Flow (Base Generation)	Maximum Turbinated Flow (Peak Generation)	Volume of Reservoir	Weighed Mean Power	Energy
	m <sup>3</sup> /s	m <sup>3</sup> /s		m <sup>3</sup> /s	m <sup>3</sup> /s	Hm <sup>3</sup>	MW	Gwh/year
Central 1	2.9	2	2	4	6.66	0.7	3.81	33.35
Central 2	3.47	4.5	4	18	30	55.91	31.63	277.05

Table 2	<b>Results Pelton</b>	Generation I	Machines for the	Compensator ]	Reservoir and	Potrero del	Clavillo
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The power and energy results are presented in Table 3.

Table 3 Results	of Power and	l Energy with	<b>Pelton Machines</b>
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Total Weighed Mean Energy	MW	35.4
Total Energy	Gwh/año	310.4
Value of Annual Mean Energy Generated	Mu\$S	52.1

#### 6. Conclusions

The study of optimization for the system of Multipurpose Complex of Rivers Las Cañas - Gastona - Medina power plants showed that the power generated by the plant system can be optimized without increasing costs and that the application of these tools during the design stage facilitates decision-making before going forward with the development of the final detailed project.

The simulation models used represent the behavior of the basin correctly, constituting a useful tool in determining design flows. This information helps assess the suitability of existing projects and provide useful information for decision making and the future design of the operating and control elements.

The hydropower optimization model allows for a layout of comprehensive operation of the system prior to the construction of the system. This allows conducting market research that is better adjusted during the drafting stage, adjusting the various designs, observing the effect of considering environmental variables that are now considered essential in works of this scale.

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