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APPLICATION OF AN OPTIMIZATION MODEL FOR THE WATER MANAGEMENT UNDER CLIMATE SCENARIOS OF THE LAGUNILLAS INTEGRAL SYSTEM OF THE PERUVIAN ALTIPLANO

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ABSTRACT

The main aim of this research work is to apply an optimization model for the management under climate scenarios of the multipurpose Lagunillas Integral System, located in the Peruvian Altiplano using the WEAP linear programming methodology that satisfies the water demand of the system. In this optimization, concepts such as financial analysis were used, comparing the cost-benefit ratio processed by the WEAP allocation algorithm and evaluating the water supply preference options for each project and that due to these economic reasons will have the highest priority. The process of generation of scenarios for the modeling of the system was made in the first place under real conditions with historical information and under the influence of climate change considering the climate projection of greater influence CANESM2-RCP4.5 and CNRM_CMI4.5 and considering 3 scenarios of operation: 1) Running only reservoir Lagunillas; 2) Running reservoir Lagunillas with water transfer from the Verde river and 3) Running reservoir Lagunillas and reservoir Verde river. The results obtained for the first scenario, show that the Cabanilla and Cabanilla - Chatapujio Project have the highest net benefits, for the other scenarios, the net benefits increase. The optimization with proposed linear programming shows that in addition to increasing the efficiency of water use in reservoirs, the levels of volume stored in the Lagunillas and Verde reservoirs are maintained more uniformly. Likewise, with the optimization it is possible to satisfy the demands raised to 100% with the operating scenario of the two reservoirs of Lagunillas and Verde river.

Keywords: Optimization; climate change, WEAP; Economic benefits, reservoir operation

1 INTRODUCTION

The water resource is the basis for human survival, social development and environmental maintenance (Meng, Wang, & Li, 2018). However, because of the rapid growth of the human population, socio-economic development (Zhang, Jin, & Yu, 2018), has led to excessive water exploitation, resulting in a shortage of water resources in the long term (Asghar, Iqbal, Amin, & Ribbe, 2019). The planning and management of water resources systems are sensitive to the distribution and temporal and spatial availability of water (Haguma, Leconte, Krau, Côté, & Brissette, 2015; Recio Villa, Martínez Rodríguez, & Soto Ramos, 2017). Climate change is now a major environmental and development problem, and will increase the challenge of sustainable management of water resources (Jin et al., 2018; Zhou et al., 2018).

Therefore, the operation of water resources systems must include spatial and temporal variations in the components of the system, such as flows and water allocation objectives, and fluctuations can be associated with the net benefits (Huang, Li, Chen, Bao, & Zhou, 2010). Because of this, the sets of global circulation models (GCM), scenarios and regional climate models (RCM) are used as input to the hydrological model to generate a future flow (Asghar et al., 2019; Men, Wu, Liu, Hu, & Li, 2018) that can be used as input for system operations.

Several studies related to the operation of reservoirs for irrigation were published using linear programming techniques (Ahmad & Tang, 2016; Singh, 2015); (Awadallah & Awadallah, 2014) implemented a multi-criteria decision approach to determine the most appropriate water release policy and capacity of water bypass facilities. Some applied the influence of climate change (Asghar et al., 2019; Jin et al., 2018); (Ngo, Masih, Jiang, & Douven, 2018) applying the Soil Water Assessment Tool (SWAT) and Water Evaluation and Planning (WEAP) models found that the operation of the reservoir leads to an increase in water discharge. dry season and a decrease in the discharges of the wet season. The monthly flow regime exhibits considerable changes for the Sesan and Srepok rivers, but with different magnitudes and patterns of increase and decrease. Like

(López-García, Manzano, & Ramírez, 2017), they used WEAP in scenarios of climate change in Mexico, similar to (Maliehe & Mulungu, 2017) that used SWAT and WEAP.

The Lagunillas Integral System, is referred to a set of hydraulic works of greater infrastructure for the water use of the waters of the river basin of the Cabanillas river, that will make possible the incorporation to the irrigation of 30,844.00 ha, distributed in ten (10) sectors of irrigation, with the regulated waters of the Ichocollo river in the Lagunillas reservoir and tributaries of the Cabanillas river (Pilares et al., 2018). The Lagunillas dam allows the storage of water resources of approximately 650.2 km2 (Figure 1).

The objective of this research work is to optimize the water availability of the multipurpose Lagunillas integral system, located in the Peruvian Altiplano through the application of an optimization model for the water management of the Lagunillas and Verde reservoirs using the linear programming methodology of WEAP that satisfies the water demand of the system.

2 METHODOLOGY

The application of the WEAP Linear Programming methodology has been considered, as it is one of the most important optimization models and because it uses more simplified conceptions of the system for an integrated planning and analysis of water resources policies, presenting an analysis module financial, allowing the user to investigate cost-benefit comparisons for projects, for which he presents water use policy scenarios in which he evaluates a wide range of water development and management options taking into account the uses of resources water.

2.1 Location

The Cabanillas river basin, is a tributary of the Coata river, which flows into lake Titicaca (Figure 1) is located geographically at 15°30'S and 70°30'W. This basin has areas of contribution above the reservoirs Lagunillas and Verde, which are the main source of storage, with a predominantly cold climate, with variable altitudes of 3840 to 4750 meters above sea level. The average precipitation is in the order of 600 mm to 800 mm. The hydraulic scheme of the Lagunillas Integral System, Figure 2, includes a storage reservoir in the lagoon Lagunillas, already built and in operation, and different systems of catchment, conduction and distribution of water in the process of implementation, which allow the irrigation of the different sectors (Pilares et al., 2018).

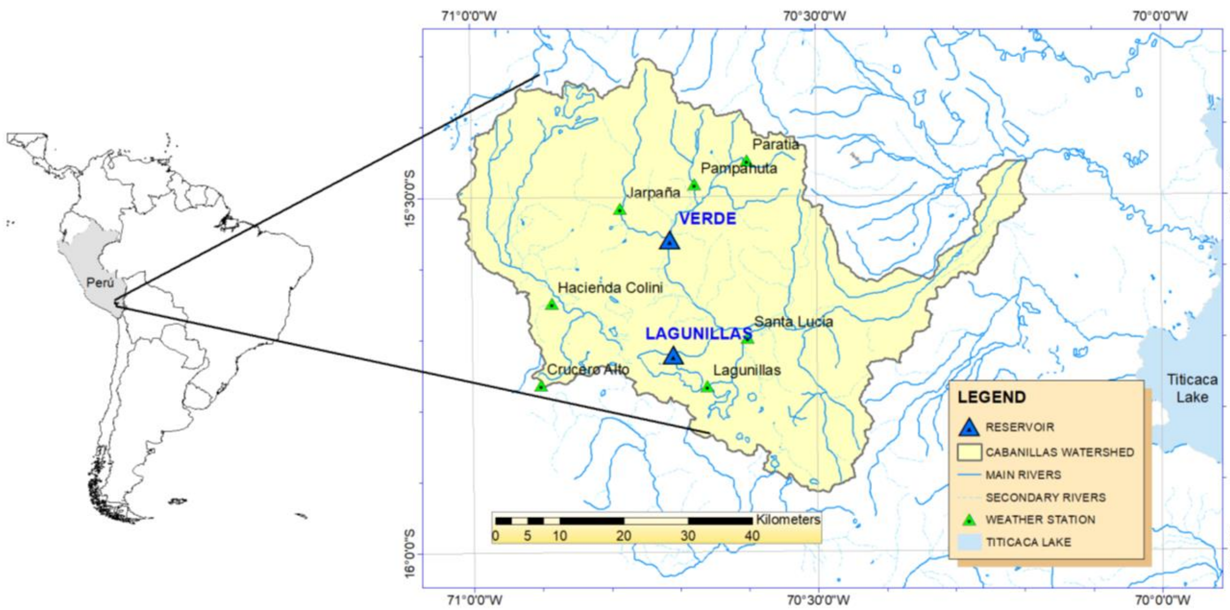

Figure 1. Geographic location of the Cabanillas basin

2.2 Modeling with linear programming

WEAP (Sieber & Purkey, 2015) uses an open-source linear program called lpsolve solver. The program and its documentation can be found online: http://sourceforge.net/projects/lpsolve. It is a linear program (LP) and is used to maximize demand satisfaction for multiple uses of the integral system of Lagunillas, subject to priorities, supply preferences and others therefore it can be said that the LP solves all the simultaneous equations mentioned above.

The conditions of this optimization are: a) The volume of water released from the reservoir must not have less than the water demand in each irrigation area. b) The volume of water storage in the reservoirs must not exceed the upper rule curve of each tank. Having the objective function, which is the linear function and all the conditions are like the linear forms. The mathematical model is follows equation 1.

$$\text{Min:}\sum_{r\in R} c_r f_r \qquad [1]$$

where,

R is a set of residues in the area, the tank water flow throughout, r ∈ R, and c is the dependence on the volume of water released from the reservoir.

With the following conditions:

The reservoirs have the condition of mathematical model that is given by equation 2.

$$S_{t+1} = S_t + I_t - R_t \qquad [2]$$

where,

S_t is the storage volume of water in the deposit at time t, I_t is the water input volume of the deposit during time t, R_t is the volume released from the reservoir water during time t.

The water released from the reservoir has sufficient volume for the demand of water use. So, D ≤ R, where D is the demand for downstream.

The penalty of the water supply that water storage does not exceed the upper rule curve and is not inferior to the curve of the lower rule of the deposit (Equation 3),

$$S_t^{lower} \le S_t \le S_t^{upper} \qquad [3]$$

where,

There are conditions as follows:

$$0 \le \text{R-D} \le 100; \quad c = 0,$$
$$100 < \text{R-D}; \quad c = 1000,$$
$$\text{R-D} < 0; \quad c = 100000$$

is the lower rule curve of the deposit over time *t* y S_t^{upper} is the upper rule curve of the deposit in the S_t^{lower} and time *t*. If the volume of water released from the reservoir is greater than the downstream demand within 1-100 hm3, then the penalty is 0. If the volume of water released from the reservoir is greater than 100 hm3 than the downstream demand, then the fine is 1,000. If the volume of water released from the reservoir is less than the downstream demand, then the penalty is 100,000.

In addition, there are more variables of the objective function for the decision where R_b is the volume of water released from the Lagunillas reservoir, R_s is the volume of water released from the Verde river reservoir, S_b is the volume of water storage in the reservoir of Lagunillas, Ss is the volume of water storage in the reservoir of the Verde River, and R_b + R_s is the volume of water released from the Lagunillas reservoir, including the volume of the Verde reservoir. In this case study area, the mathematical model is given by equation 4.

$$\text{Min=}\sum_{i=1}^{12} cb_i R_b + \sum_{i=1}^{12} cs_i R_s \qquad [4]$$

where,

$$3800 \le Sb_i \le 13462 \qquad 2850 \le Ss_i \le 9510$$

cb_i = Penalización por el agua liberada embalse Lagunillas.

cs_i = Penalizacion por agua liberada de embalse Verde.

2.3 Objective function and priorities for water allocation

The objective function of this operational optimization of the reservoir is to reduce the water flow rate in the downstream areas. WEAP strives to maximize the water supply, allocating according to the priorities and preferences of the supply demand. Reiterating that WEAP for each priority and preference, allocates water with priority 1 and others with priority 2. Thus, the LP resolves at least once for each priority in each time step, because the objective is to maximize the coverage rate of all the demands of the projects. In cases where there is not enough water to satisfy all the demands with the same priority, WEAP tries to satisfy all the demands with the same percentage of its demand.

2.4 Modeling for costs and benefits

WEAP provides the function of the model for the calculation of variables such as "cost" and there are a series of parameters such as annualized "cost of capital", "cost of operation and maintenance variables" per unit of water, "fixed costs of operation and maintenance" annualized. The variable "benefit" can be accessed in a similar way as the cost variables, the benefits that can be modeled in WEAP, are the "variable benefits" or variable returns and the "fixed benefits" known as current benefits or benefits. return. The benefits can also be entered for each individual element, both fixed (annual) and variable (per unit flow). Annual benefits are distributed evenly over the time steps of the year to obtain a benefit for each time step, such as the net present value (NPV) of future capital expenditures and net operating costs of any benefit, considering the internal rate of return (IRR).

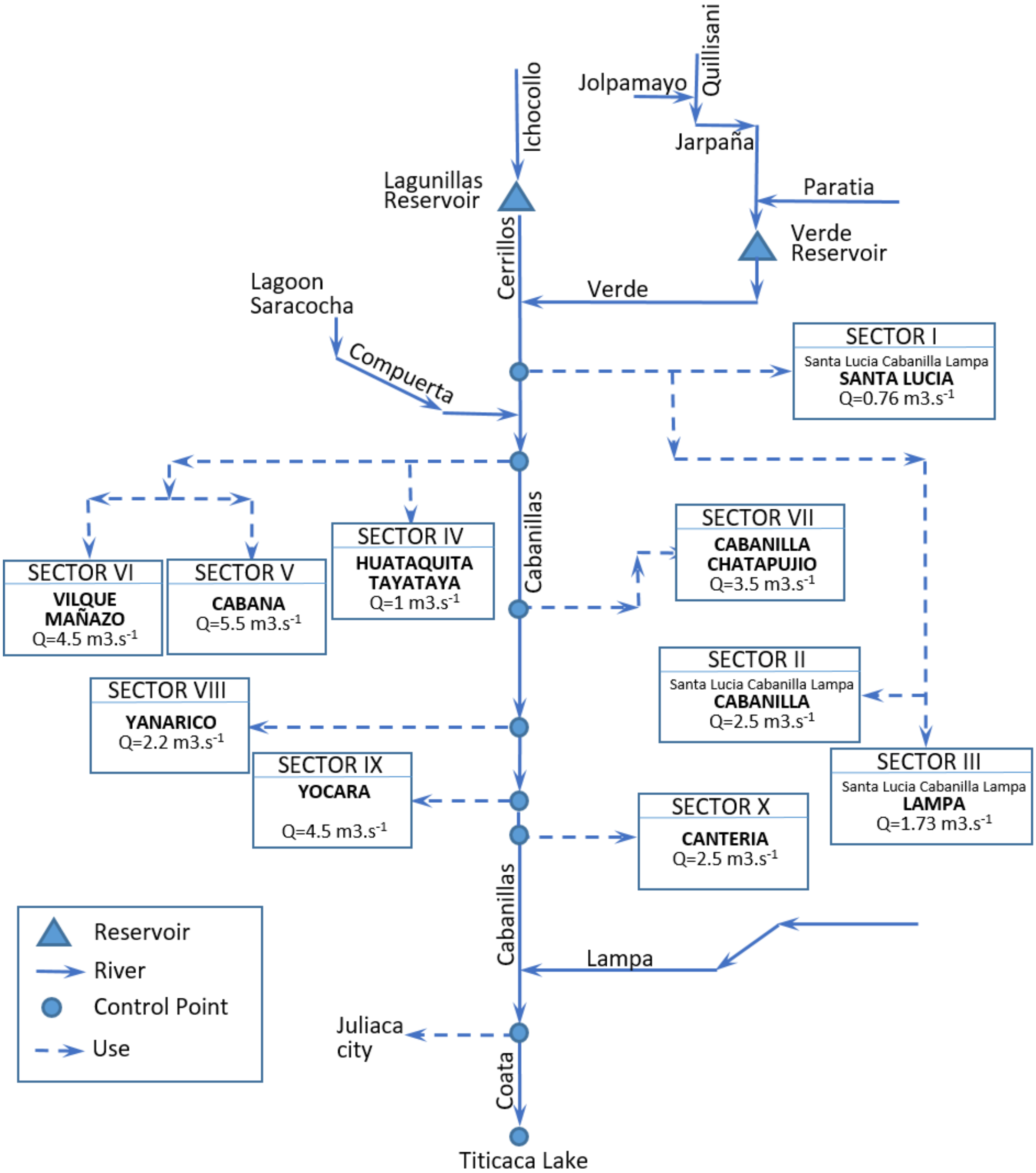

Figure 2. Hydraulic diagram of the reservoir modeling, river and uses of the Lagunillas integral project.

2.5 Historical and future data

The data from 7 rainfall stations located within the Cabanillas basin were used as input for the baseline simulation and to calibrate and validate the WEAP model. For the analysis, two reservoirs of multipurpose use were selected in the Cabanillas basin. The elevation-volume curves of the reservoirs were obtained from the Proyecto Especial Binacional Lago Titicaca (Lake Titicaca Binational Special Project, PEBLT) (Pilares et al., 2018). Hydrometeorological data were obtained from the Servicio Nacional de Meteorologia e Hidrologia (National Service of Meteorology and Hydrology) (SENAMHI, 2019).

Three scenarios of the reservoir input data were analyzed: (1) historical records of observed scenarios and RCP (1994-2008); (2) the near future period (2011-2040), the medium future period (2041-2070) and the far future periods (2071-2100). Simulating historical (past) and future reservoir entries using precipitation and temperature projections of the combined results of CANESM2_RCP 4.5 for the southern peruvian domain under two recent representative concentration pathway (RCP4.5 and RCP8.5) climate scenarios.

The water demand of the Lagunillas Integral System includes: a) Population use of the cities Puno, Juliaca and Lampa, b) Irrigation, c) Industrial development - mining and d) ecological demand of the Lagunillas Integral System, which represents a total demand of 643,674 hm3 year^{-1}, of which irrigation represents 79.40% of the total water demand of the system (Pilares et al., 2018).

2.6 Elaboration of costs and benefits of projects of the Integral System Lagunillas

Table 1 shows the costs of the irrigation projects of the Integral System Lagunillas, which was obtained from institutions of the Gobierno Regional de Puno (Regional Government of Puno, GRP), Programa Regional de Riego y Drenaje (Regional Program of Irrigation and Drainage, PRORRIDRE), Proyecto Especial Binacional Lago Titicaca (Special Binational Lake Titicaca Project, PEBLT) and the Ministerio de Economia y Finanzas (Ministry of Economy and Finance, MEF) in its investment consulting platform (MEF, 2018), from which the pre-feasibility, feasibility and definitive studies of the 10 irrigation sectors included in the Lagunillas Integral System were obtained. The costs are expressed in dollars according to the exchange rate given by the Superintendencia Nacional de Administracion Tributaria (National Superintendency of Tax Administration, SUNAT) and Table 2 shows the benefits of the system.

Table 1. Costs of the sectors of the Integral System Lagunillas in Dollars.

PROJECT	AREA (ha)	VOLUME (m3s-1)	COSTS			
			COST OF CAPITAL ($)	FIXED OPERATING COSTS ($)	COST OPERATION ($)	TOTAL COST ($)
VILQUE- MAÑAZO	4,820.0	4.80	10’748,355.48	11’757,015.90	5’845,628.98	28’380,791.52
CABANA	5,405.0	5.50	8’797,140.28	8’061,468.20	2’605,145.23	25’267,508.48
HUATAQUITA	1,000.0	1.00	2’030,118.02	2’671,640.64	2’358,816.25	7’060,574.91
YANARICO	3,174.5	2.20	3’542,645.23	53,109.54	1’246,771.73	4’842,526.50
CANTERIA	2,077.0	3.20	904,270.67	20,773.50	563,957.60	1,489,001.77
SANTA LUCIA	990.0	0.76	15’562,704.24	5,226.15	925,557.92	15’748,057.60
CABANILLA	3,100.0	2.50	48’731,701.06	31,226.15	551,314.49	49’314,241.70
LAMPA	2,250.0	1.73	36’265,818.02	26,576.33	378,222.61	36’670,616.96
YOCARA	4,030.0	3.50	15’192,786.57	261,161.84	1’797,704.59	17’251,651.94
CABANILLA - CHATAPUJIO	3,600.0	3.50	5’981,980.57	161,007.77	482,838.52	6’625,826.86

Table 2. Benefits of the sectors of the Integral System Lagunillas in Dollars.

PROJECT	BENEFITS					
	FIXED ($)	BY WATER UNIT ($)	IRR (%)	NPV ($)	B/C	TOTAL BENEFIT ($)
VILQUE- MAÑAZO	12’580,007.01	17’787,439.91	0.30	5’038,457.95	1.07	30’367,446.93
CABANA	9’270,688.43	19’786,946.33	0.16	5’795,959.01	1.15	29’057,634.75
HUATAQUITA	3’205,968.76	5’266,721.13	0.12	3’054,402.83	1.20	8’472,689.89
YANARICO	60,013.78	5’412,041.17	0.16	384,993.99	1.13	5’472,054.95
CANTERIA	39,677.38	2’804,315.99	0.30	590,106.01	1.91	2’843,993.37
SANTA LUCIA	6,323.64	9’048,826.05	0.12	4’293,984.45	1.21	19’055,149.69
CABANILLA	40,593.99	64’067,920.21	0.13	8’922,516.25	1.30	64’108,514.20
LAMPA	49,166.20	67’791,475.18	0.12	7’335,879.86	1.85	67’840,641.38
YOCARA	339,510.39	22’087,637.14	0.15	3’091,288.34	1.30	22’427,147.53
CABANILLA - CHATAPUJIO	196,429.48	7’887,079.28	0.15	753,137.10	1.22	8,083,508.76

2.7 Modeling of the system for 3 operating scenarios

It analyzes storage and demands raised to 100% with influence of climate change: CANESM2-RCP4.5, CNRM_CMI4.5 and historical. In addition, three (3) storage operation scenarios and demands were assumed:
- Working only with storage of the Lagunillas reservoir
- Working with water transfer from the Verde River to the Lagunillas reservoir; and

- Working with Lagunillas reservoir storage and the Verde River reservoir.

3 RESULTS

The results of the water use priorities for the historical information scenarios 1994 to 2008 and future from January 2011 to 2100 are shown in Table 3.

Table 3. Priorities for water use based on financial analysis modules according to scenarios.

OPERATING SCENARIO		PROJECTS WITH WATER PRIORITIES BASED ON FINANCIAL ANALYSIS MODULES			
		Net Benefits	**Capital costs**	**Operating costs**	**Demand for Water allocated**
1. ONLY WITH STORAGE OF RESERVOIR LAGUNILLAS	**HISTORICAL**	1. Cabanilla 2. Cabanilla–Chatapujio 3. Huataquita	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Vilque-Mañazo 3. Cabanilla	1. Cabanilla 2. Cabanilla – Chatapujio 3. Huataquita
	CANESM2_RCP4.5	1. Cabanilla 2. Cabanilla–Chatapujio 3. Huataquita	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Cabana 3. Cabanilla	1. Cabanilla 2. Yocara 3. Yanarico
	CNRM-CMI-RCP4.5	1. Cabanilla 2. Cabanilla–Chatapujio 3. Huataquita	1. Cabanilla 2. Lampa 3. Santa Lucia	1. Vilque-Mañazo 2. Cabana 3. Cabanilla-Chatapujio	1. Cabanilla-Chatapujio 2. Cabana 3. Yocara
2. WITH WATER TRANSFER FROM THE VERDE RIVER TO LAGUNILLAS RESERVOIR	**HISTORICAL**	1. Cabanilla 2. Cabanilla–Chatapujio 3. Lampa	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Vilque-Mañazo 3.Cabanilla-Chatapujio	1. Cabanilla 2. Yocara 3. Lampa
	CANESM2_RCP4.5	1. Cabanilla 2. Lampa 3. Yanarico	1. Cabanilla 2. Lampa 3. Yocara	1. Cabanilla 2. Yocara 3. Cabanilla-Chatapujio	1. Cabanilla 2. Yocara 3. Yanarico
	CNRM_CMI_RCP4.5	1. Cabanilla 2. Lampa 3. Yanarico	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Cabana 3. Cabanilla-Chatapujio	1. Cabanilla 2. Yocara 3. Yanarico
3. WITH STORAGE OF LAGUNILLAS RESERVOIR AND VERDE RIVER RESERVOIR	**HISTORICAL**	1. Cabanilla 2. Canteria 3. Yocara	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Vilque-Mañazo 3. Cabana	1. Cabanilla-Chatapujio 2. Yocara 3. Cabana
	CANESM2_RCP4.5	1. Cabanilla 2. Cabanilla–Chatapujio 3. Yanarico	1. Cabanilla 2. Lampa 3. Yocara	1. Cabana 2. Yocara 3. Cabanilla-Chatapujio	1. Cabanillas 2. Cabana 3. Yocara
	CNRM_CMI_ RCP4.5	1. Cabanilla 2. Cabanilla–Chatapujio 3. Huataquita	1. Cabanilla 2. Lampa 3. Yocara	1. Yocara 2. Cabana 3. Cabanilla-Chatapujio	1. Cabanilla-Chatapujio 2. Cabana 3. Yocara

3.1 First scenario: Working only with storage of Lagunillas reservoir

It can be seen from Table 3 and Figure 3 that the Cabanilla, Cabanilla-Chatapujio and Huataquita projects present the highest net benefits, both with historical information, as well as the climate change scenarios CNRM_CM5_RCP4.5 and CANESM2_RCP 4.5. The lowest benefit project is Canteria.

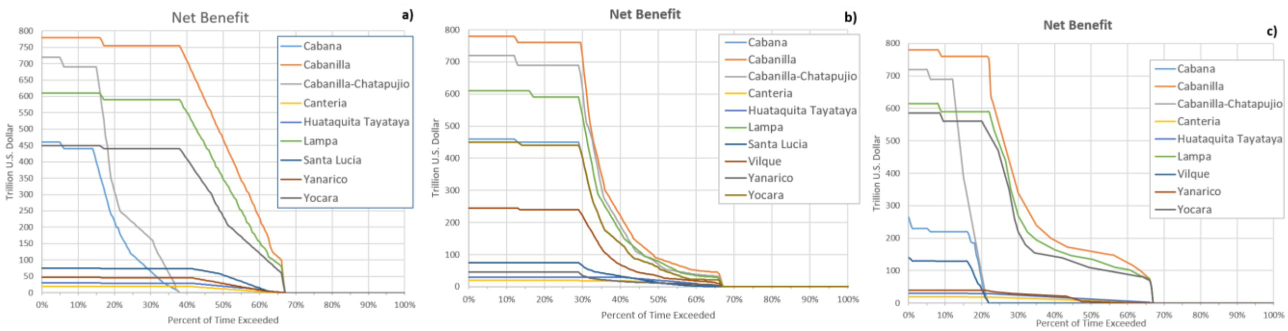

Figure 3. Net benefits with climate scenarios a) CNRM_CM5-RCP45, b) CANESM2-RCP45, c) Historical

Table 3 shows that the projects with Yocara, Vilque-Mañazo and Cabanilla projects have the highest operational cost, both with historic information and with the climate change scenarios CANESM2_RCP 4.5 and CNRM_CM5_RCP4.5, and the lowest operating cost is Yanarico.

The projects with the highest cost of capital, both with historical information and with the climate scenarios, are the Cabanilla, Lampa and Yocara projects. The projects with Yanarico and Cantería are the ones with the lowest cost of capital.

The priority of water demand allocated, with historical information is 18% and the most representative climate change, CNRM_CM5-RCP4.5, in 35% are the Cabanilla, Cabanilla-Chatapujio and Huataquita projects (Table 3 and Figure 4).

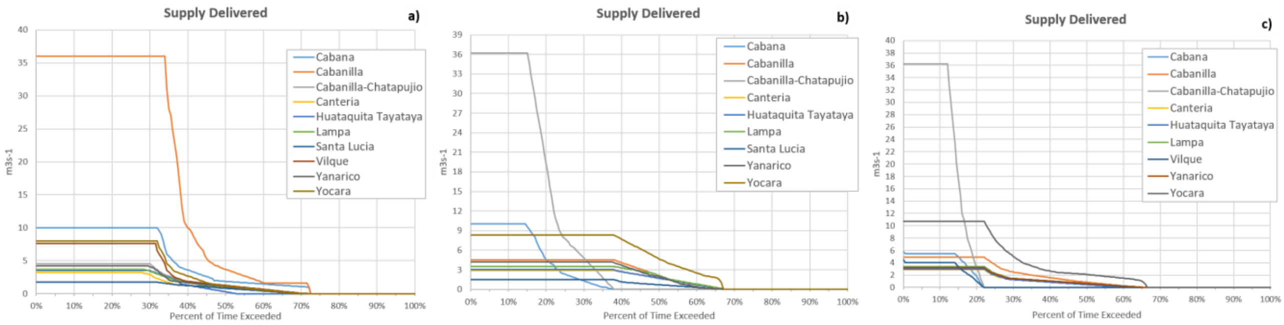

Figure 4. Demand covered by scenario a) CNRM_CM5-RCP4.5, b) CANESM2-RCP4.5 c) Historical

3.2 Second scenario: Working with water transfer to the Lagunillas reservoir.

As shown in Table 3 and Figure 5, the largest net benefits with historical information are the Cabanilla, Cabanilla-Chatapujio and Lampa projects, which with respect to the first scenario increased by 10% persistence. Under the influence of climate change with CANESM2_RCP 4.5 and CNRM_CM5_RCP 4.5 the projects with the highest net profit are Cabanilla, Lampa and Yanarico with 45% and 50% with respect to the historical information, while the one with the lowest net profit is the Cantería project.

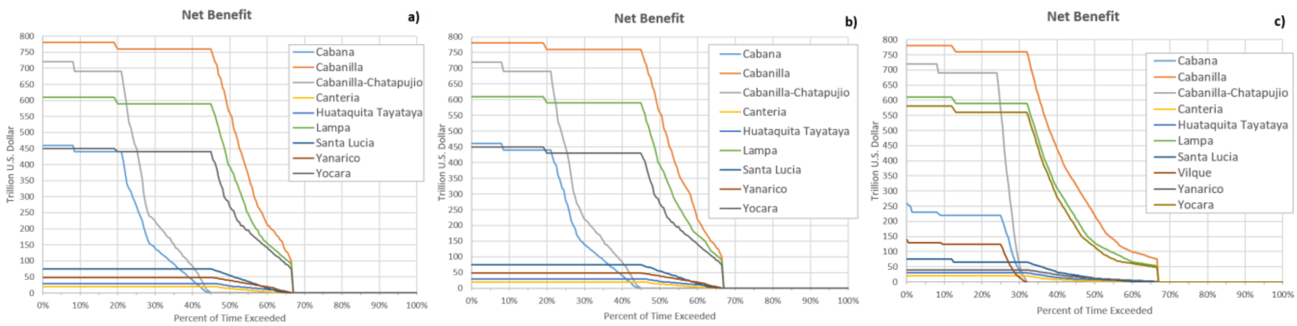

Figure 5. Net benefits with scenarios a) CANESM2-RCP4.5, b) CNRM_CM5-RCP45 and c) Historical

From Table 3 it can be observed that the operating costs are high for the Yocara and Cabanilla - Chatapujio, Cabanilla projects and the lowest cost for the Canteria project. In terms of capital costs are higher for Cabanilla, Lampa and Yocara in that order. The lower costs for the Cantería y Yanarico projects.

The demand for water allocated with both historical information and climate change increases by 20% with respect to the first scenario. with historical information at 38% persistence, with the climate change scenario CANESM2-RCP4.5 reaches 75% persistence (Figure 6).

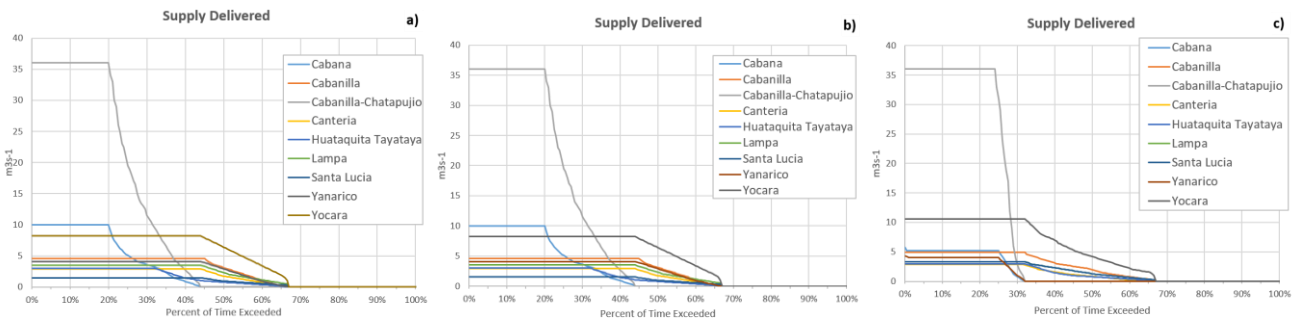

Figure 6. Demand covered by scenarios a) CNRM_CM5-RCP4.5, b) CANESM2-RCP4.5 and c) Historical

3.3 Third scenario: Working with storage of the Lagunillas reservoir and the Verde river reservoir.

The net benefits are greater, with historical information the Cabanilla, Canteria and Yocara projects while under the influence of climate CANESM2_RCP4.5 and CNRM_CMI_RCP4.5 the projects of Cabanilla, Cabanilla - Chatapujio, Yanarico, are with greater net benefits, with an increase of 20% with respect to the second scenario, that is, 95% and 100%. The one with the lowest net benefit is the Lampa project (Table 3 and Figure 7).

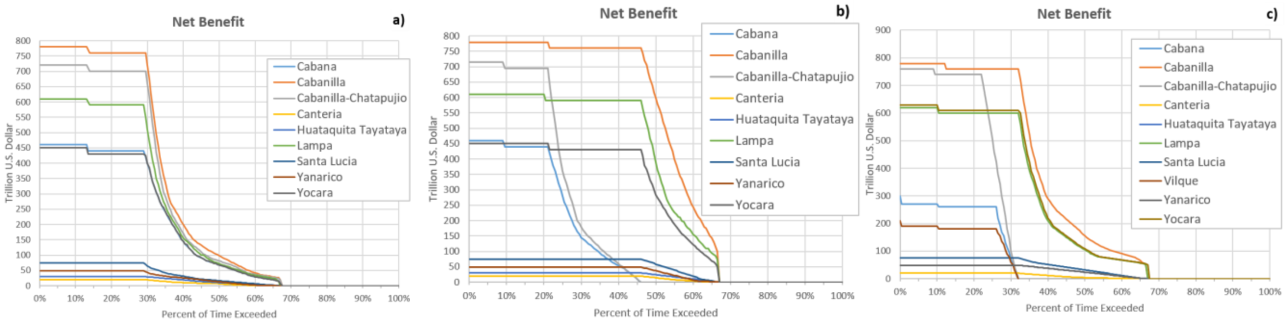

Figure 7. Net benefits with scenarios a) CNRM_CM5-RCP45, b) CANESM2-RCP45 and c) Historical

The operating costs are greater both with historical information and with the influence of climate change on the projects of Cabana, Yocara and Cabanilla-Chatapujio. The lower operating cost of the Yanarico project. The highest capital costs are presented to the Cabanilla, Lampa and Yocara projects for the three operating scenarios.

The demand for water allocated goes up by 20% with respect to the second scenario with historical information such as climate change, with historical information increases by 58% persistence. With the climate change scenario CANESM2-RCP4.5 reaches a 90% persistence (Figure 8).

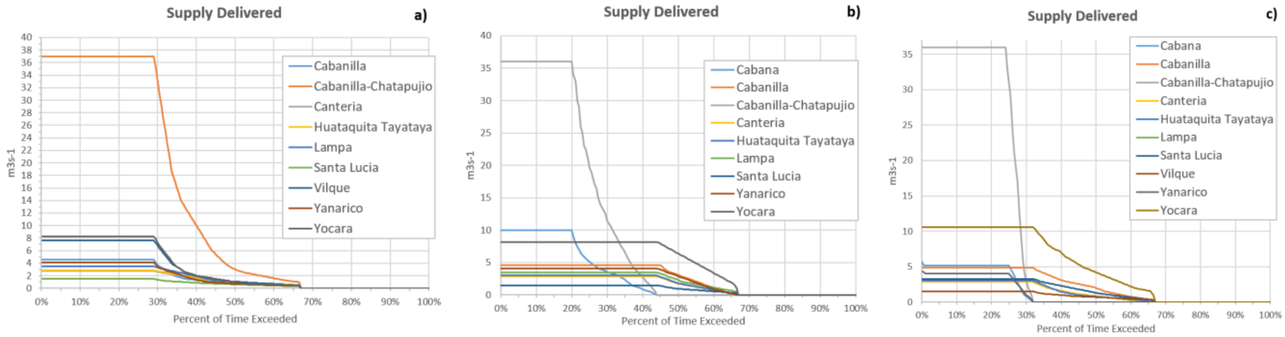

Figure 8. Demand covered by scenarios a) CNRM_CM5-RCP4.5, b) CANESM2-RCP4.5 and c) Historical

3.4 Volumes of the Lagunillas reservoir.

3.4.1 Scenario working only the Lagunillas reservoir

In the three operating scenarios, it does not present an overflow, reaches 450 hm3 with historical information, reaches 480 hm3 with CANESM2-RCP4.5 and reaches 530 hm3 with CNRM-CM5-RCP4.5, varying linearly from 10% to 55%. maintain a level of 35 hm3 (Figure 9).

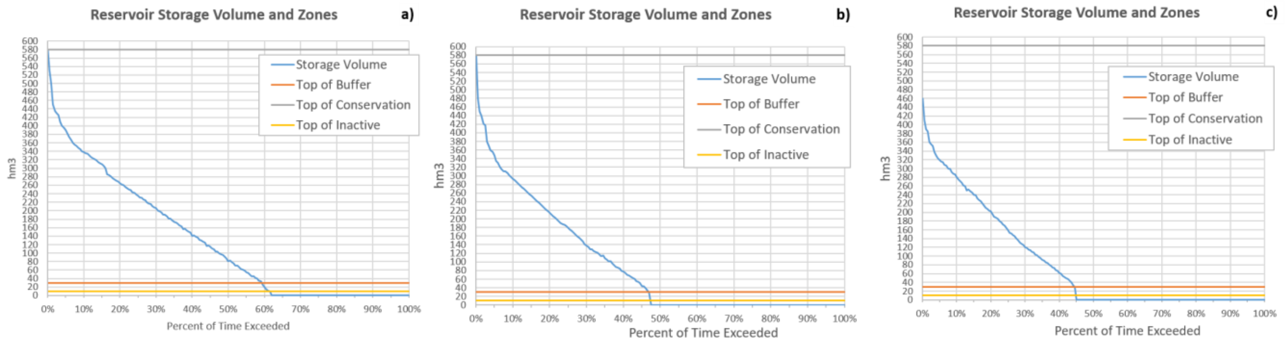

Figure 9. Volumes of the Lagunillas reservoir under the climate change scenario a) CNRM_CM5-RCP4.5, b) CANESM2-RCP4.5 and c) Historical

3.4.2 Volumes for scenario working with the transfer of the Rio Verde to the Lagunillas reservoir

The volumes of the reservoir Lagunillas with transfer of the waters of the Verde river to the Lagunillas reservoir, have in the three operating scenarios an overflow of 10% after filling 580 hm3 and vary linearly 10% to 55% to then maintain a level 35 hm3 (Figure 10).

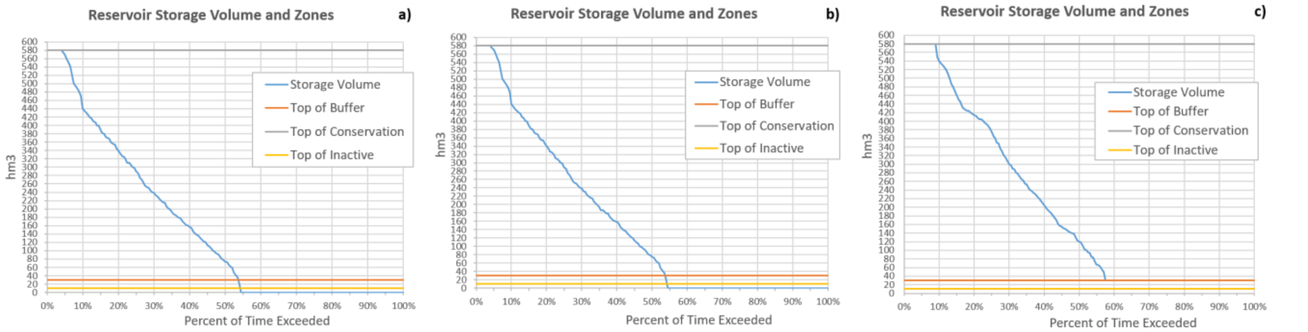

Figure 10. Volumes of Lagunillas with Verde river transfer for scenarios a) CANESM2-RCP4.5, b) CNRM_CM5-RCP4.5 and c) Historical

3.4.3 Volumes for operating scenario reservoir of Lagunillas and reservoir of the Verde river

The volumes of the reservoir of the Verde river has an overflow of 15% of persistence up to 55% to 68% varying linearly and later is maintained with 250 hm3, plus the contribution of the reservoir of Lagunillas of 500 hm3, it would have a total of 750 hm3, shown in Figure 11.

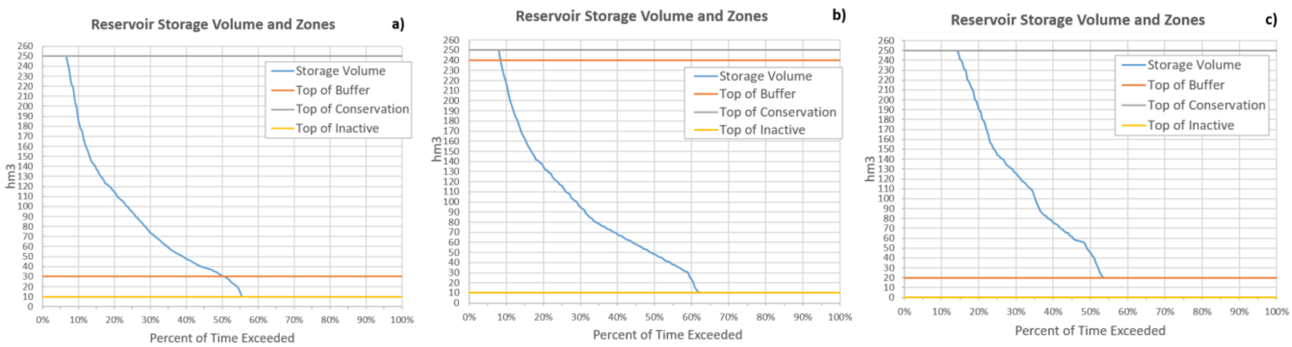

Figure 11. Volumes in Lagunillas and Verde reservoirs for scenarios a) CANESM2-RCP4.5, b) CNRM_CM5-RCP4.5 and c) Historical

4 CONCLUSIONS

Based on a linear programming and optimization proposed by WEAP, it is concluded that the projects of Cabanilla, Cabanilla-Chatapujio will have the first priority of the water resource of the Integral System of Lagunillas, mainly due to the high net benefits, while the Cantería project has the lower net benefits, both with historical information and under the climate scenarios proposed for the 3 operating scenarios.

The optimization of operation with linear programming proposed, shows that in addition to increasing the efficiency of water use in reservoirs, the levels of volume stored in the reservoirs Lagunillas and Verde River are maintained more uniformly. Likewise with the optimization it is possible to satisfy the demands raised to 100% with the operating scenario of the two reservoirs of Lagunillas and the Verde river, shows that in addition to increasing the efficiency of the use of water in the reservoirs, they are more uniformly maintained. volume levels stored in the reservoirs and the levels of volume stored in the reservoirs of Lagunillas and Verde river are maintained more evenly. The volumes of the reservoir of the Verde river have an overflow of 15% persistence up to 55% to 68% varying linearly and later is maintained with 250 hm3, aditionally the contribution of the reservoir of Lagunillas of 500 hm3, it would have a total of 750 hm3 .

Finally, this research work applying linear programming and optimization with WEAP is the first to be applied for the Lagunillas Integral System, recommending the application of other methods such as dynamic programming, Fuzzy Logic, among others.

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