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Partial use of the surface of Corani reservoir (Cochabamba, Bolivia) and proposal of sustainability indicators[1]

Aprovechamiento parcial de la superficie del embalse Corani (Cochabamba, Bolivia) y propuestas de indicadores de sustentabilidad

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Abstract: During the dry season, part of the surface of the artificial Corani hydroelectric reservoir in Cochabamba, Bolivia, is dry and is used by farmers to grow mainly "potatoes" (*Solanum tuberosum*). Images from the 1990-2021 period were studied and it was estimated that the cultivated areas range from 6.18% to 43.52% of the total lake. The cultural practices applied are adapted to the short time available. The activity does not affect electricity production. The farmers are descendants of the former owners of the land, exercising a kind of factual hereditary right over the land. Under these conditions, it is concluded that the negative environmental impact "loss of flooded land" (Irreversible), can acquire the character of Mitigable. Temporary occupation of the reservoir is proposed as a mitigation measure for artificial reservoirs. To evaluate the sustainability of an artificial hydroelectric reservoir, two indicators are proposed: the temporary availability of dry land suitable for agriculture and the Power Density average of the hydroelectric project, for full and partially dry reservoir scenarios.

Key words: Social impacts reservoirs, factual hereditary rights, Power Density average

Resumen: En época de estiaje queda seca una parte de la superficie del embalse artificial hidroeléctrico Corani, en Cochabamba - Bolivia, la cual es aprovechada por agricultores para cultivar principalmente "papa" (*Solanum tuberosum*). Se estudiaron imágenes del periodo 1990-2021 y se estimaron que las superficies cultivadas van del 6,18% al 43,52% del total del lago. Las prácticas culturales aplicadas están adaptadas al corto tiempo disponible. La actividad no afecta a la producción de electricidad. Los agricultores son descendientes de los antiguos propietarios de los terrenos, ejerciendo una forma de Derecho hereditario factico sobre los terrenos. En estas condiciones, se concluye que el impacto ambiental negativo "pérdida de terrenos inundados" (Irreversible), puede adquirir el carácter de Mitigable. Se plantea la Ocupación temporal del embalse como una medida de mitigación para embalses artificiales. Para evaluar la sustentabilidad de un embalse artificial hidroeléctrico se proponen dos indicadores: la disponibilidad temporal de superficie seca para agricultura y la Densidad de Potencia promedio del proyecto hidroeléctrico, de los escenarios embalse lleno y parcialmente seco.

Palabras claves: Impactos sociales embalses, Derecho hereditario factico, Densidad de Potencia promedio

1 Introduction

In the department of Cochabamba, Bolivia, the national electricity company ENDE built the Corani artificial reservoir in the 1960s to supply water to the Corani and Santa Isabel hydroelectric plants. Before the construction of the reservoir, the valley floor was used for agriculture. The reservoir is developed at 3.245 m a.s.l. (maximum level), with 1.420 ha flooded and a storage volume of 142 million m^3 (ENDE Corani, 2023). The dam is located on the Corani River, downstream of the city of Colomi; it receives water from the upper basin of the Colomi, Kanko, Candelaria and Kayarani Rivers and, since the end of the 1990s, from other basins. After Santa Isabel, the San José 1 and San José 2 power plants were built in 2019. This is a cascade hydroelectric system, with a single reservoir and four successive power plants.

As an annual regulation reservoir, it stores water during the rainy season and contributes to meet the requirements of the national electricity system. Towards the south and southwest, the relief consists of an extensive plain with a low slope.

It has been observed that some months of the year, during the dry season, the water level retraction to the north, drying out the south and southwest of the reservoir, which is used by farmers to plant some crops, mainly potatoes (Solanum tuberosum). This activity seems to be consolidated, as it is repeated year after year and there is no opposition from social organizations or the power company.
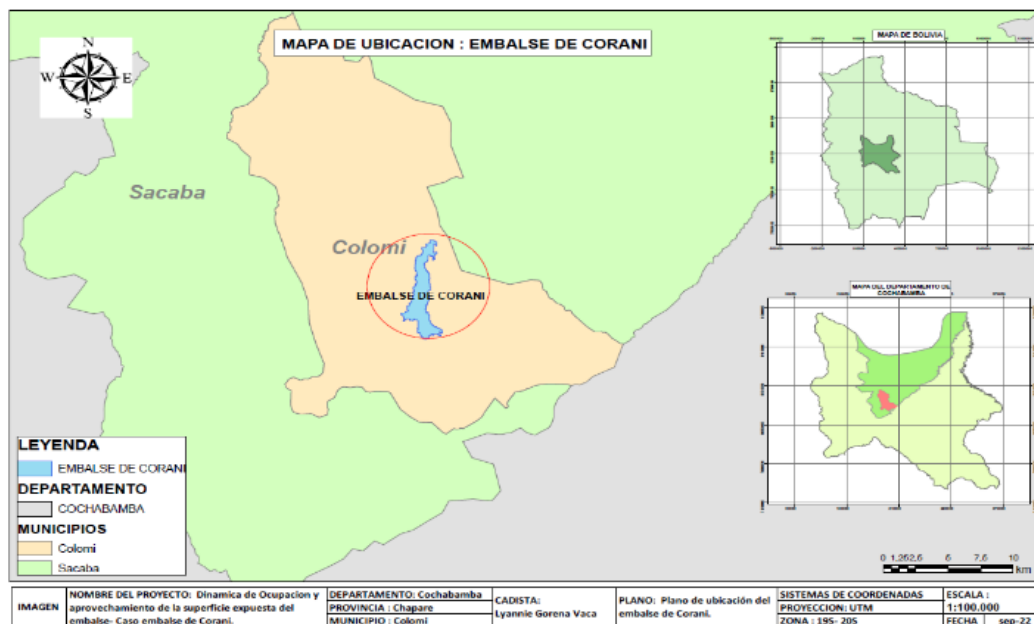

Figure 1: Location of the study area.

Similar situations of partial and temporary land occupation of an artificial lake are not reported (see for example, IFC, 2018; IHA, 2018; van der Ploeg & Vanclay, 2017; ENERGETICA, 2020). Currently, it is not described how the activity of partial occupation of the Corani reservoir lands is developed, how it is inserted in the regional agricultural calendar, its eventual environmental and social implications and, being that the loss of land caused by an artificial reservoir is one of the most significant irreversible negative environmental impacts, it is pertinent to study if it can constitute an environmental mitigation measure.

In this context, the research aims to study the partial and temporary use of the lands that occur in the reservoir during low water levels (dry season), to improve the socio-environmental management of hydroelectric projects. The objectives are:

- To study the characteristics of the partial and temporary agricultural use of land by farmers in the reservoir area when there are dry areas usable for agriculture. Analyze its implications.

- Propose an environmental mitigation proposal for the irreversible loss of soils, due to the creation of the reservoir.

- Propose environmental indicators that reflect the sustainability of the hydroelectric project, due the temporary use of the reservoir soils in agriculture.

2 Methodology

2.1 Satellite image processing

For the processing of satellite images, the intersection of geographic information layers of LANDSAT 5 and 8 images, available in USGS EarthExplorer (USGS, 2022), was carried out. For image classification, the spatial, spectral, temporal, and radiometric resolution, and the maximum percentage of cloudiness in the image (maximum 10-20%) were considered for the period 1990 to 2021, which,

considering such restrictions, were reduced to 24 years studied. The geoprocessing for the combination of the multispectral bands was performed with ArcGIS software; then the vectorization/digitization of the total surface of

the Corani reservoir was performed with a total surface of the lake (full reservoir) and partially dry (low water), year after year.
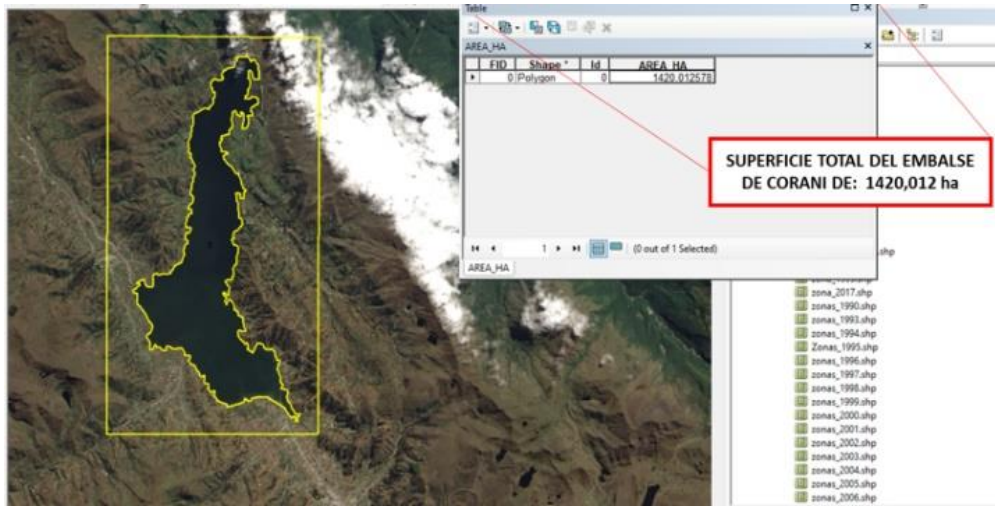

Figure 2: . Model for quantification of the total surface area of the Corani reservoir.

The vectorization/digitization focused on the areas of the reservoir corresponding to the communities of Candelaria, Kanko and Tumuyo, to the southwest and south of the reservoir, because these are the dry areas that are used for agriculture.

Figure 3: Communities located to the southwest and south of the Corani reservoir, which are drying up.

2.2   Soil analysis

To corroborate the suitability of the soils for agriculture, soil samples were taken and processed by the Soil and Water Laboratory of the Faculty of Agricultural, Livestock and Forestry Sciences of the Universidad Mayor de San Simón. Samples were taken from three points of land that flood during the rainy season (Candelaria-Kanko, Tumuyo) and from a control point that does not flood (Candelaria sector).

The soil sampling coordinates of the cultivated area and the control plot are shown below.
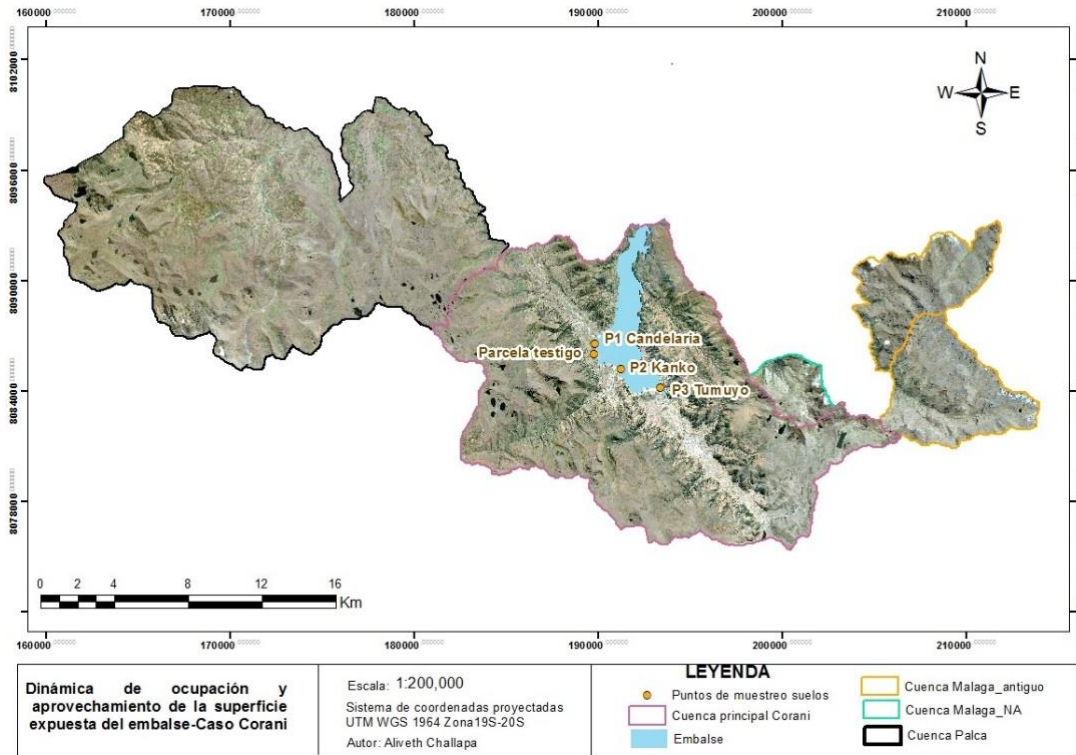
Figure 4: Soil sampling map.

Table 1. Soil sampling coordinates (08/19/2022).

Sampling points	Coordinates UTM, 20K		Texture			Classification
	X	Y	Clay %	Silt %	Sand %	
Control	189709.0	8086037.4	24	46	30	Silty
P1	189756.8	8086613.4	10	50	40	Silty Loam
P2	191183.2	8085244.8	15	35	50	Silty
P3	193308.1	8084223.8	14	56	30	Silty Loam

2.3   Determination of Power Density

To determine the environmental sustainability of the hydroelectric project, the Power Density was calculated for the following scenarios: i) full reservoir (design, rainy season) and ii) partially empty (dry season).

To apply to the specific case, the Power Density has been calculated considering the four power plants of the system fed by the Corani reservoir (Corani, Santa Isabel, San José 1, San José 2). The power of the plants has increased over time because of repowering, the addition of generating units or the commissioning of new plants; therefore, the total power varies over time. Power data was obtained from National Dispatch Center (CNDC) and was expressed in megawatts or watts (MW, or W).

The surface area of the full reservoir is one. The water surface during the dry season varies from year to year. Therefore, there are two water surfaces per year: rainy months (full, approximately 6 months) and dry months (partially dry, approximately 6 months). The two surfaces are expressed in Hectares or square meters (Has, or m^2).

The basic equation for the calculation of the Power Density is as follows:

$$PD = \frac{P}{S}$$

Where:

PD: Power Density (W/m², or MW/ha)

P: Installed power at the hydroelectric power plant (W, or MW)

S: Reservoir Surface (m², or ha)

The two Power Densities were calculated for the full and partially dry reservoir scenarios.

3   Results and analysis

3.1   Characterization of the temporary use of the reservoir and agricultural calendar

The area of the reservoir that dries up and becomes available for agriculture is dependent, in time and space, on the withdrawal of water (Figure N° 5), which begins from March-April onwards, reaching its maximum area in approximately August-September each year. The surface area varies from year to year as it depends on the hydrological regime and the operation of hydroelectric power plants.

Figure 5: Corani reservoir and exposed area for agriculture.

Photo 1: Agricultural use Candelaria sector: Area planted (12/2/2021), flooded (04/06/2022) and prepared for planting (08/19/2022), respectively.

The agricultural calendar starts in August when land preparation is carried out; sowing takes place in the same month. Conventional cultural practices common in the region are applied, including the use of fertilizers and pesticides. Harvesting takes place in February-March of the following year, mainly conditioned by the constant increase in the water level of the reservoir due to rainfall; harvesting is usually carried out gradually, starting with those rows closest to the reservoir water and leaving the peripheral rows for the end, thus extending the growing

season. If the water increase is more rapid and the crop is not yet mature, then it is harvested and marketed as fodder.
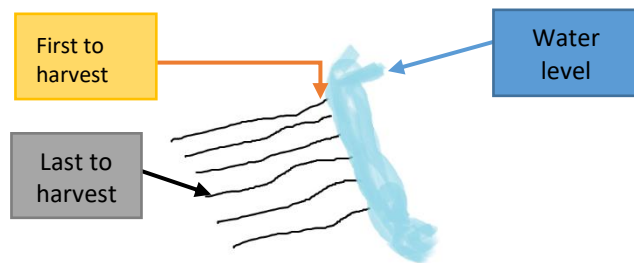

Figure 6: Crop harvesting scheme in the furrows of the reservoir flooded area.

The agricultural calendar is like the one applied throughout the region, although it is much more widespread in the region[2].

Table 2. Crop calendar scheme in the region and in the reservoir.

Agriculture activity	In the surrounding region	On the reservoir lands
Seeding	May - September	August
Crop development	October - March	August - February
Harvest	March - June	February - March

A closer look revealed that not all the dry land is used for agriculture; it is estimated that 20% of the dry land is natural accidents that impede agriculture ("roads", muddy areas, riverbanks, river streams).

The quantification of the exposed and therefore dry surfaces, those that are cultivated and the reservoir that remains with water left over, is presented in Table Nº 3.

Of the total area of the full reservoir, 1,420 ha, the dry area ranged from 13.94% in 1990 (minimum dry area) to 61.95% in 2004 (maximum dry area). In other words, in 2004, 879.93 Ha dried up and became available for agriculture, leaving only 540,27 ha available for hydropower generation. The inter-annual variation shows the tendency of the dry surface to increase in recent years, which is generally of the order of 40%. This percentage is

very significant and shows the high potential for agriculture in the reservoir area.

If we exclude the non-cultivable areas for the years mentioned, the cultivated area ranges from 6,18% (1990) to 43,52% (2004) of the total reservoir, i.e. in 2004, only 617,97 ha of the reservoir were cultivated, out of the potential 879,93 ha. The cultivated area is relevant.

3.2 Crops

The most widely grown crops are "potatoes" (*Solanum tuberosum*, varieties "waycha" or "holandesa"), "broad beans" (*Vicia faba*), "oca" (*Oxalis tuberosa*), "barley" (*Hordeum vulgare*), "oats" (*Avena sativa*), which is consistent with the crops grown in the region. Production is mainly, but not exclusively, sold on the local market.

In the reservoir, cultural practices aimed at shortening the growing season can be observed, such as the planting of "potatoes" with some root development (see Photography N° 2, Kanko plain). This is considered to be a strategy in response to the short agricultural calendar, i.e. a crop with a short vegetative cycle, as anticipated by Navia (2008).

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[2] Personal communication, Eng. Franz Terrazas, PROINPA

Table 3. Estimation of dry, effectively cultivated and remaining water areas. Maximum lake surface (full reservoir): 1.420 ha.

| Year | Dry surface ha | | | | | | Dry surface Percentage % | Percentage of cultivated area % | Remaining surface with water [Has] |
| | Candelaria-Kanco | | Tumuyo | | All | | | | |
	All	Cultivated	All	Cultivated	All	Cultivated			
1990	125,37	59,26	72,64	28,49	198,01	87,75	13,94	6,18	1221,99
1991	130,49	92,34	104,44	67,73	234,93	160,07	16,54	11,27	1185,07
1993	204,73	166,89	117,26	108,24	322,00	275,13	22,68	19,38	1098,01
1994	320,37	187,22	165,92	130,25	486,30	317,47	34,25	22,36	933,71
1995	219,70	146,94	114,64	109,58	334,33	256,52	23,54	18,06	1085,67
1996	177,76	133,53	184,79	139,74	362,55	273,27	25,53	19,24	1057,45
1997	169,07	131,86	96,58	94,04	265,64	225,90	18,71	15,91	1154,36
1998	168,41	97,02	204,53	108,32	372,94	205,34	26,26	14,46	1047,07
1999	335,02	257,13	231,68	199,19	566,70	456,32	39,91	32,14	853,30
2000	268,81	202,07	219,26	178,05	488,07	380,12	34,37	26,77	931,93
2001	279,97	212,42	141,51	119,90	421,47	332,31	29,68	23,40	998,53
2002	279,53	217,06	168,84	142,93	448,37	359,99	31,58	25,35	971,63
2003	382,87	267,61	283,81	270,97	666,68	538,58	46,95	37,93	753,32
2004	557,33	395,57	322,41	222,41	879,73	617,97	61,95	43,52	540,27
2005	207,71	136,92	129,68	119,24	337,39	256,16	23,76	18,04	1082,61
2006	343,44	283,14	321,10	272,81	664,55	555,95	46,80	39,15	755,45
2010	291,05	203,65	204,84	178,43	495,90	382,08	34,92	26,91	924,10
2014	340,80	284,11	329,53	303,27	670,33	587,38	47,21	41,36	749,67
2015	277,74	217,03	323,12	269,22	600,86	486,24	42,31	34,24	819,14
2016	322,57	275,49	337,94	290,04	660,50	565,53	46,51	39,83	759,50
2017	293,54	221,84	232,70	183,25	526,24	405,09	37,06	28,53	893,76
2019	309,92	237,74	286,71	216,52	596,64	454,26	42,02	31,99	823,36
2020	389,61	289,47	298,47	247,43	688,08	536,91	48,46	37,81	731,92
2021	313,55	302,29	332,31	309,74	645,87	612,03	45,48	43,10	774,13

Photo 2: Characteristics of the "potato" sown, Candelaria sector, with root development (08/19/2022).

Table 4. Results of soil análisis.

Parameters		Dry season								Rainy season			
		P1		P2		P3		Control		P1	P2	P3	Control
		08/19/2022	11/15/2022	08/19/2022	11/15/2022	08/19/2022	11/15/2022	08/19/2022	11/15/2022	4/8/2023	4/8/2023	4/8/2023	4/8/2023
pH		5,5		5,4		4,6		5,7		5,1	5,2	4,6	5,7
Conductivity	(momhs/cm)	0,15		0,06		0,29		0,05		0,163	0,147	0,687	0,071
Nitrogen total	%	0,09		0,12		0,19		0,37		0,144	0,133	0,149	0,394
Phosphorus available	ppm	36,9		23,5		20,1		10,8		66,9	69,2	70,9	51,2
Potassium available	me/100 gr	0,2		0,46		0,16		0,29		0,23	0,39	0,55	0,37
Organic matter	%	1,41	1,87	0,92	1,75	2,01	3,51	9,61	8,18	2,82	2,47	2,82	9,96
Field capacity	%	12,76		15,57		16,49		12,69		15,88	16,12	18,51	21,76

Agriculture is carried out in such a way that it does not affect the main activity, which is hydroelectricity, with no perceived incompatibilities.

3.3 Soil quality of the cultivated area

The physical properties of the soil in the study area, as well as the physic-chemical parameters, indicate that they are suitable for "potato", "broad bean" and "pea" agriculture. This is consistent with the characteristics of the ecological floor of Puna, as well as with the taxonomy of the soils.

The control plot is permanently fallow and has a natural vegetation layer, so its organic matter content is higher, while in the other three plots natural fertilizers such as "chicken manure", "rice husk" and other N-P-K fertilizers are applied. Navia (2008) confirms that 18-46-0, "chicken manure", or "urea" fertilizers are indeed often used. The possible impact of nutrients on soil and water quality deserves further study.

Compared to the control plot, the Phosphorus and Nitrogen analyses suggest that the addition of fertilizer

guarantees high "potato" yields. It has been observed that the macronutrient Potassium is one of the most limiting nutrients in crops (Toledo, 2016), being more susceptible to leaching due to the influence of the reservoir drainage (Cáceres, 2022). Comparing the control plot and the cultivated plots, the differences could be attributed to the fact that the former is a resting soil and not subject to flooding, so the soil structure is more stable and has a medium porosity.

At the beginning of the rainy season, an increase in the organic matter parameter is observed. This is confirmed by the fact that the herbaceous plant "chamomile" *(Matricaria chamomilla)*, which is characterized by growing in fertile soils rich in organic matter (Ministry of Sustainable Development, 2003), was widely observed in the study area.

Therefore, the soil quality of the flooded land is suitable for agriculture in terms of its physical and chemical properties. Farmers also say that good yields are obtained.

3.4 Access to flooded land: de facto right of inheritance

One aspect that needed to be clarified was how access to the reservoir land would be determined, given that the land is owned by the electricity company. In the field, it was found that there was no controversy over access and that it was accepted by the social organizations.

According to the information gathered, access to the reservoir land is by the descendants of those who once owned the land when the reservoir was created and expanded in the 1960s - 1990s, i.e. to date, essentially the third generation. Such access is without legal title to the land. On the site there are forms to demarcate the land (Photography N° 3).

This access would demonstrate that the right to occupy and use the land has not been extinguished, despite the transfer of title to the electricity company. This suggests that there is a "de facto right of inheritance". It could be interpreted that the former *stakeholders* of the past, the owners of the flooded land, are regaining roles and importance through their descendants.

Photo 3: Demarcation of land on the reservoir site.

One aspect that needs to be studied is how these land access rights are transmitted or inherited to other generations.

3.5 Mitigation proposal: Temporary occupation of the reservoir

The first negative, direct, irreversible environmental impact of the creation of an artificial reservoir is the loss of soil, with all that this implies: the displacement of the human population, their activities and belongings, the loss of services, cultural, socio-economic, tourism and biological resources, among others (IFC, 2015). It therefore challenges to find mitigation measures.

The use of an area of the reservoir initially lost by flooding, even temporarily, constitutes a migration from *irreversibility* of the negative impact to *mitigability*, thus reducing the severity of the negative impact.

Based on this case study, it is proposed to consider as a mitigation measure **the temporary occupation of the reservoir area**, under controlled conditions and when the characteristics of the reservoir and the hydroelectric

activity allow it. The situations and conditions that would allow it are shown in Table N° 5.

This measure allows:

- Decrease the area effectively lost by the creation of a reservoir and thus the severity of negative environmental impacts.

- Improving the sustainability of the hydropower Project.

- Re-establishing the lost productive system and social links. A source of income is created.

- Contributing to the social acceptance of the project.

Table 5. Mitigation of loss of flooded area: temporary land occupation (favorable situations and conditions).

Situations that must arise to consider temporary occupation of the reservoir	Conditions that would make the temporary occupation of the reservoir acceptable
The reservoir basin is made up of large areas that are susceptible to temporary dryness	It does not affect the quality of water, soil or increase sediment transport. It does not increase the emission of greenhouse gases.
A seasonal hydrological regime, with alternating rainy and dry periods.	Socially acceptable
That the operating regime of the power plants may lead to months of higher consumption of the dammed water.	That it generates benefits for the population
That the dry period coincides with the agricultural calendar, thus allowing for temporary occupation of the soil	Use species commonly grown in the region and vicinity, preferably native species
	No conflict of interest between agriculture and electricity generation.

3.6 Proposal of environmental indicators

The creation of an artificial reservoir, in addition to the positive impacts inherent in the motivation for the project, has widely recognized negative environmental and social impacts, including the loss of flooded land.

Within the framework of this research and with the elements collected, two indicators are proposed that can be incorporated into the environmental management tools for artificial reservoirs.

3.6.1 Indicator Temporary surface availability

The direct indicator for determining the possibility of using this mitigation measure is the **availability of usable area for agricultural activities**.

In the case of new hydropower projects, it is possible to determine at the study stage whether there will be land available for agricultural use if (see also Table N° 5):

- The bathymetry and characteristics of the basin suggest that there may be areas that could be used for agriculture.

- Soil quality is suitable for agriculture.

- The rainfall and water use regime leads to periods of low water levels.

- There are not affected the water requirements by the hydroelectric power plant.

In the positive case, it is plausible to consider temporary land occupation as a mitigation measure. The larger the usable agricultural area, the higher and more significant the contribution of the mitigation measure will be. Figure N° 7 shows the decision flow chart.

3.6.2 Indicator Average Power Density

The sustainability of a hydropower project can be determined through the Power Density (PD) indicator, which expresses the ratio between the power of the hydropower plant and the surface area flooded to satisfy the requirements of the plant[3]. The higher the ratio, the more sustainable the hydropower project will be.

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[3] Earlier literature used the ratio "flooded area/Power" (sometimes referred to as "Ecological Impact Index"), but more recently, "Power/flooded area", a definition of Power Density, has become widely used.
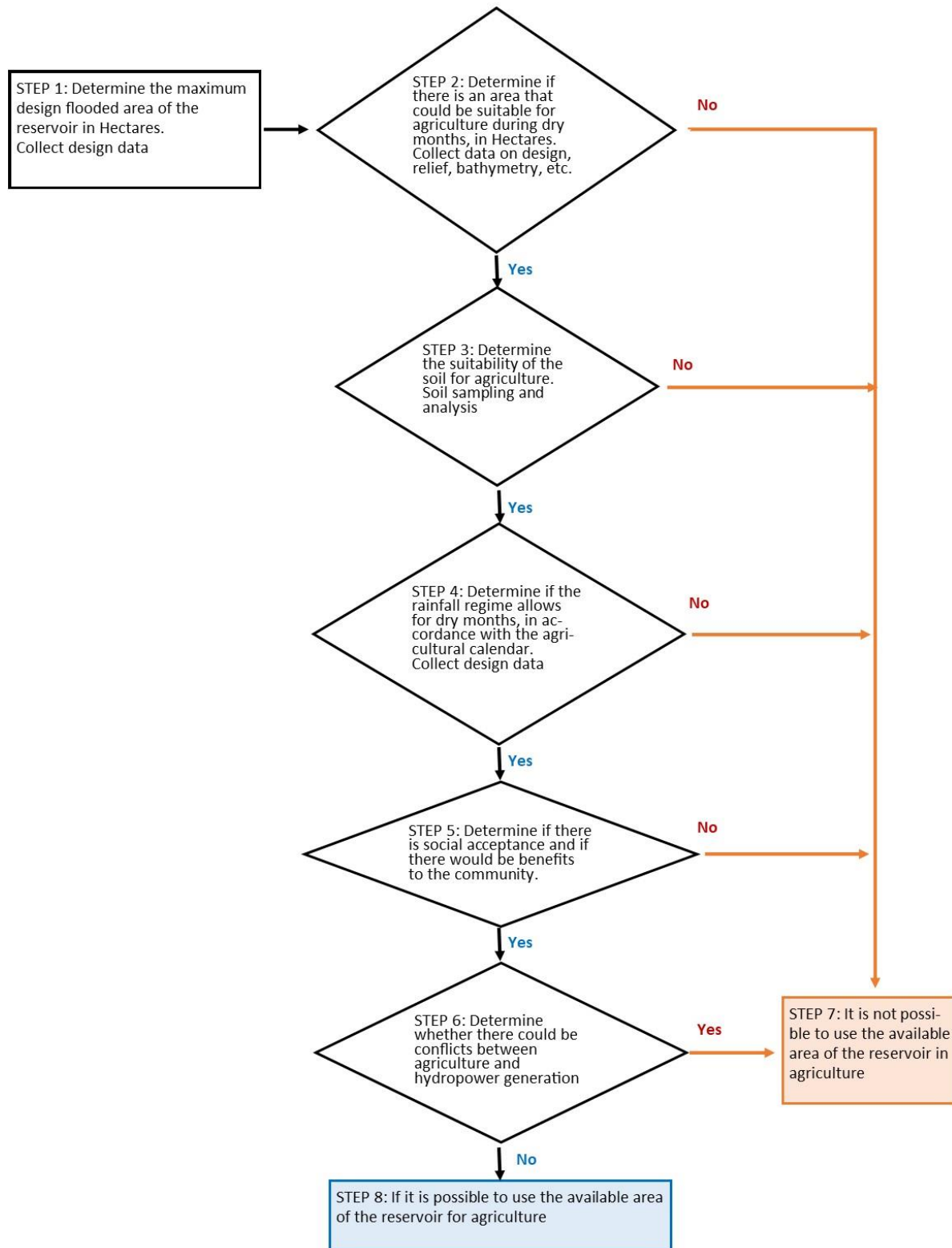
Figure 7: Determination of the availability of usable land.

Table 6. Calculation of Power Density, with full and remaining reservoir (Power is the sum of the four power plants: Corani, Santa Isabel, San José 1 and San José 2). Maximum lake surface (full reservoir): 1.420 ha. C: Corani Hydro plant, S: Santa Isabel Hydro plant, SJ1: San Jose 1 Hydro plant, SJ2: San Jose 2 Hydro plant.

Year	Remaining surface with water [Has]	Power in Hydroplants C, S, SJ1, SJ2 MW	Power Density of full reservoir W m^{-2}	Power Density of remaining surface W m^{-2}	Average Power Density W m^{-2}
1990	1.221,99	126,00	8,87	10,31	9,59
1991	1.185,07	126,00	8,87	10,63	9,75
1993	1.098,01	126,00	8,87	11,48	10,17
1994	933,71	126,00	8,87	13,49	11,18
1995	1.085,67	126,00	8,87	11,61	10,24
1996	1.057,45	126,00	8,87	11,92	10,39
1997	1.154,36	126,00	8,87	10,92	9,89
1998	1.047,07	126,00	8,87	12,03	10,45
1999	853,30	126,00	8,87	14,77	11,82
2000	931,93	126,00	8,87	13,52	11,20
2001	998,53	126,00	8,87	12,62	10,75
2002	971,63	126,00	8,87	12,97	10,92
2003	753,32	127,80	9,00	16,96	12,98
2004	540,27	144,90	10,20	26,82	18,51
2005	1.082,61	144,90	10,20	13,38	11,79
2006	755,45	147,00	10,35	19,46	14,91
2010	924,10	148,73	10,47	16,09	13,28
2014	749,67	148,73	10,47	19,84	15,16
2015	819,14	148,73	10,47	18,16	14,32
2016	759,50	148,73	10,47	19,58	15,03
2017	893,76	148,73	10,47	16,64	13,56
2019	823,36	280,35	19,74	34,05	26,90
2020	731,92	280,35	19,74	38,30	29,02
2021	774,13	280,35	19,74	36,21	27,98

In the usual calculation this indicator considers only the full reservoir as the only scenario. However, as described in this case study, the water surface in the reservoir may be less in some months of the year (dry season), so that the PD is higher than in other months of the year.

Currently, the Corani reservoir feeds four hydroelectric power plants arranged in cascade: Corani, Santa Isabel, San José 1 and San José 2, i.e. there is only one reservoir (one flooded area) to serve the turbines of four power plants. Table N° 6 shows the PD calculated for the two scenarios, expressed in W m^{-2}.

The Power Density has a one value when the reservoir is full, and another, higher value when the reservoir is partially dry - and cultivated. By way of example, for the year 1990, the DP = 8,87 W m^{-2} considering the reservoir full (rainfall), rises to 10,31 W m^{-2} with the reservoir partially dry (low water) and, for the year 2004, DP = 10,20

W m^{-2} rises to 26,82 W m^{-2}, respectively[4]. Environmental sustainability improves, because for the same installed capacity in the power plants, the area flooded is smaller[5].

The two Power Densities have an approximate duration of half a year each (for full and partially dry reservoir, 6 months each). The actual Power Density calculated for a hydroelectric project should reflect both scenarios. Therefore, it is proposed to calculate the arithmetic average of the two scenarios. Generalizing and considering the possibility of different time periods (full and dry months), so that the influence of these can be weighted, the formula for *average Power Density* would be:

$$PDa = \frac{Mf}{Mt} * \frac{P(100)}{Sf} + \frac{Md}{Mt} * \frac{P(100)}{Sr}$$

Where:

PDa: Power Density average [W m^{-2}]

Mt: 12, total Months of the year (Mf + Md)

Mf: Number of Months with full reservoir (design)

Md: Number of Months with dry reservoir (observed or estimated)

P: Installed power in hydroelectric plant [MW]

Sf: Full Surface Reservoir [Hectare] (design)

Sr: Surface of reservoir with remaining water during dry season [ha] (observed or estimated)

The "*average power density*" of the reservoir will allow a better characterization of the sustainability of the hydropower project.

4   Conclusions

a) Agriculture is practiced in the temporarily dry areas of the artificial reservoir of Corani, in an area that varies from year to year, depending on the rainfall regime and the operation of the hydroelectric plants. The maximum dry area observed during the period under study was in 2004, when it reached 61,95% of the lake (1.420 ha), while the area actually cultivated reached 43,52%, corresponding to 617,97 ha.

Cultural practices have been adapted to the conditions imposed by the climate, the length of the rainy season and the dynamics of water use by the hydroelectric plant, without affecting it.

Agriculture is at farmer's risk.

b) Today's farmers are the descendants of the former landowners who were flooded when the artificial reservoir was created and who were compensated financially or in kind, thus creating a *de facto right of inheritance*.

The access to the land has been socially accepted by the villagers as well as by the electricity company.

Soil quality is suitable for agricultural development, especially for tubers. The application of fertilizers and pesticides could alter water and soil quality.

c) The negative environmental impact of soil loss caused by the creation of the artificial reservoir, conceptually considered irreversible, can be considered *mitigable* and applicable in certain cases in the light of this research. Therefore, it is proposed to consider it as a mitigation measure when dealing with the creation of reservoirs.

In addition to the social benefits of this measure, it contributes to greater efficiency of the hydroelectric complex.

It is conceivable that a reservoir designed as a single-purpose reservoir (in this case hydroelectric) could acquire a broader character, even migrating to a multi-purpose reservoir, as it would serve the requirements of other sectors, such as agriculture in this case.

d) In cases where the artificial reservoir partially dries up, there are two Power Densities of approximately half a year each: i) calculated with the full reservoir, and ii) calculated with the reservoir partially dry. This leads to an improvement in environmental sustainability, as the flooded area is smaller in some months of the year for the same installed capacity. The *average Power Density* of both scenarios is proposed as an indicator of real

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[4] Climate Bonds Initiative (2021). Eligibility criteria for environmentally sustainable hydropower projects: DP > 10 W m^{-2} for projects that started operation in 2020 or later, and DP > 5 W m^{-2} if built before 2020.
In the case under study, the reference value of 5 W m^{-2} should be used because the plants were built before 2020.

[5] The calculation is intended to demonstrate the changes in Power Density caused by seasonal agriculture and does not necessarily express the overall sustainability of the entire Corani hydropower system.

environmental sustainability. A calculation formula is suggested.

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