University of California, Davis

International Agricultural Development Graduate Group

Capstone Project

Towards a better understanding of the impacts of large irrigation projects: A proposal for evaluation indicators

Cristian Jordan Diaz

Faculty Adviser: Lovell Jarvis, Ph.D.

Contents

Acronyms list

CNR	National Commission of Irrigation (Comisión Nacional de Riego)
CASEN	National Socioeconomic Characterization Survey (Encuesta de Caracterización Socioeconómica Nacional)
CIREN	National Center of Natural Resources
DGA	Water General Directorate (Dirección General de Aguas)
DOH	Hydraulic Works Directorate (Direccion de Obras Hidráulicas)
INDAP	Agricultural and Livestock Development Institute (Instituto de Desarrollo Agropecuario
INE	National Institute of Statistics (Instituto Nacional de Estadísticas)
JoV	Monitoring River Committee (Junta de Vigilancia)
MINAGRI	Ministry of Agriculture (Ministerio de Agricultura)
MOP	Ministry of Public Works (Ministerio de Obras Públicas)
ODEPA	Agricultural Planning and Studying Office
PNUD	United Nations Development Program
WUA	Water User Association (Asociación de Usuarios de Agua)

Abstract

In Chile, the agricultural sector represents about 73% of water consumption, which faces problems of temporal and spatial availability, as well as certainty in the supply of this type of resource. This lack of certainty, in addition to the standard potential benefits of agricultural productivity, are the main foundations that have led to the construction of large infrastructure projects (reservoirs, canals) be called as a solution to address this problem. However, after decades of promoting such solutions, to date, there is no evidence of what the real effects of this type of work.

In this way, this project provides a proposal for a set of indicators that contribute to the quantification of impacts, as well as perform evaluation analysis on the effects of large infrastructure projects in the area where they place. To do this, first, it was identified positive and negative impacts, classifying them into five dimensions: social, economic, agricultural, environmental and land use. Then, for each dimension a set of indicators is proposed, through which it will be possible on the one hand to be able to evaluate the situation of the reservoir before and after the intervention, to determine historical trends for determined variables, as well as to be able to compare results from different projects. Thus, it will be possible to generate useful information for a series of initiatives, which can be used to support professionals and authorities in the agricultural sector concerning the implementation of public programs, as well as in the future generation of policies focused on dealing with variability and climate change.

1. Introduction

Water is an essential resource for most Chilean economic activities, being used as a production input in mining, hydropower, agriculture, among others. However, due to the Mediterranean climate that governs Chilean territory, water shows a high heterogeneity in its availability either in space and time. As a result, there are regions which are plenty of water (Southern Chile), but there are other with significant deficits, mainly from Santiago to Northern Chile (World Bank, 2011). The combination of a limited supply and increasing demands, it has caused a relative scarcity of water.

This setting of water scarcity has led to irrigation fostering as an important issue for the Chilean agricultural policy roughly four decades. Subsidies to implement efficient systems, channel construction, as well as infrastructure projects of water storage, aiming regulation and efficiency usage (Vicuna, Alvarez, Melo, Dale, & Meza, 2014). The demand for irrigation projects has also increased by a growing public and private claim for investments in irrigation as a tool to cope with current drought conditions as well as future problems of water availability due to climate variability and climate change (MININTERIOR, 2015).

For large projects, priorities have been in infrastructure provision such as dams and conveying canals. These projects seek a variety of objectives including a reduction in uncertainty in water deliveries to farmers, increases in yielding and productivity, and changes in cultivation patterns towards more profitable crops and. These changes contribute to improvements in socioeconomic conditions to whom are directly (farmers) and indirectly (e.g. local markets) recipient by a project. However, once a project is on service, state agencies reduce their action in the area. In this way, both state and decision-making authorities, and professionals involved in the agricultural sector are not aware of the real impacts of this type of intervention, losing valuable information about the productive development of the intervened territory.

In this context, this Capstone project seeks to contribute to quantifying effects/impacts of large irrigation projects in Chile, through the generation of a set of indicators that apply to each project. These indicators will allow the measurement of changes in some variables of interest, establishing a mid-long-term follow-up system for such initiatives and, as a result, producing information for supporting either authorities and professionals of the sector concerning the productive development of these areas under study.

Finally, the document breakdowns as follows. The next section (2), covers a brief description of types of irrigation interventions in Chile. Meanwhile, section 3 go through the proposal of indicators for large infrastructure projects. With this information, in part 4 some examples of indicators applied to 2 projects are presented, and finally, final comments and considerations developed in chapter 5.

2. Background

2.1. Irrigation Projects Typology in Chile

An irrigation system may be defined as a group of structures and management capacity to catch, regulate, convey and deliver water to water users of a particular irrigated area, satisfying water crops requirements (FAO, 1985). Typically, irrigation systems split into two main types: on-farm, and off-farm projects. The first corresponds basically to irrigation systems such as drip or furrow irrigation (and complements) with the objective to deliver water into the field and delivering water to the plants regarding crops requirements. On another hand, at the off-farm level, we found mainly works such that capture water from a source and then convey, distribute and regulate its usage. The following types of infrastructure are infrastructure works (MIDESO, 2016):

i. Works for water catchment: those that allow the extraction of resources from the origin and for different purposes (e.g. irrigation, industry). An example is wells to capture groundwater.
ii. Transportation Works, to capture or deviate and convey water to distribution systems.
iii. Distribution networks: second and third order canals for conveying water from the main canal to irrigation fields.
iv. Regulation works: allow the storage of water flowing during periods when not in use (winter) to use when there is a deficit mostly in summer. This category includes the dams and night regulation dams.

Large infrastructure projects are an off-farm type and characterized because they affect many economic agents, and their influence extends broad geographical zones (CNR, 2011). Due to a project affects many agents that relate each other, the probability of finding externalities that are quantitatively relevant and therefore likely to be measured is high (for instance, effects on schooling or mortality rate in the area close to the project).

2.2. National Investments System and Infrastructure Projects

In Chile, almost every large investment project is under the National Investments System (SNI) umbrella, that rules public investments in Chile, either in education, irrigation or transport. The SNI is managed by Social Development Ministry (MIDESO) and bring together norms, procedures, and methodologies that guide the planning, design, evaluation and implementation of investments applying for public funding[1].

In the irrigation arena, project initiatives are studied, planned, prioritized and presented to SNI by the National Irrigation Commission (CNR), authority formed by five ministries and an Executive Secretariat, responsible for the promotion, development, and studies related to irrigation (CNR, 2011). The planning process divides into three main stages, namely Pre-investment, Investment and Operation (MIDESO, 2016). Pre-investment corresponds to a phase in which a project is studied in different depths degree (Profile, Feasibility I, Feasibility II), meanwhile Investment stage covers Design and Implementation. Finally, Operation phase begins with Projects start-up. It is important to highlight that any project (and for any sector) needs to meet a minimum level of profitability to moves forward in the planning and design process. The minimum standing is to meet a Net Present Value (NPV) > 0 with an Intern Interest Rate (IRR) > 6% in each phase. Otherwise, a project is ruled out and does not continue to further stages (MIDESO, 2016). Therefore, the specific justification for each project is given by its technical suitability and a positive social NPV (at feasibility level) from the economic and financial evaluation standpoint. Append 1 depicts the life cycle for an irrigation project.

[1] http://sni.ministeriodesarrollosocial.gob.cl/quienes-somos/descripcion-del-sni/

2.3. Impacts and Justification of Infrastructure Irrigation Projects

In Chile, most of the economic activities use water resources. Mining, energy generation, industry, and agriculture, among others, use water as an input for production, with farming being the most demanding of water resources, with 73% of withdrawals at the national level (World Bank, 2011).

Also, Chile has a Mediterranean climate determining a heterogeneous distribution of water both throughout the country and for different seasons of the year. Rainy winters and mostly dry summers determine an imbalance in supply and demand of water for agricultural production, determining a certain relative scarcity of this resource (Vicuna et al., 2014; World Bank, 2011). Thus, promotion of irrigation has been an important subject in agricultural policy during four decades, in particular through subsidies. Subsidies are aimed to implement efficient irrigation systems (e.g. drip irrigation), channel construction and waterproofing, as well as large storage projects, allowing the regulation and a more efficient use of water (Vicuna et al., 2014). This action is strengthened by the recent drought conditions experienced by the country[2], climate change projections[3] and for a growing public and private claiming for increasing investments in irrigation, as a mean to cope with current and future problems of water availability (MININTERIOR, 2015).

Subsiding irrigation projects has its fundamentals on international evidence, where it finds that this type of projects has a wide promotion. In fact, the World Bank played an active role in encouraging large dams (for irrigation and hydropower) given the belief that this typology leads to development and poverty reduction (Duflo & Pande, 2007). In this context, in addition to these benefits, the literature mentions a range of additional gains, such as increases in productivity and income (Dillon, 2011; Van Der Berg & Ruben, 2006), vulnerability reduction to rain shortages (Duflo & Pande, 2007). Furthermore, this type of projects allows greater food security.

Smith (2004) presents an extensive list of benefits of irrigation projects. He highlights that there are four inter-related mechanisms through which irrigated agriculture can reduce poverty:

- Improvements in the levels and security of productivity, employment and incomes for irrigating farm households and farm labor;

[2] The drought has struck Central Chile, territory where the most important agricultural production is located.
[3] Climate change projections for Chile are increasing temperatures, reduction of precipitation, and changes in the seasonal water distribution.

- The linkage and multiplier effects of agricultural intensification on the wider economy;
- Provision of opportunities for diversification of rural livelihoods; and
- Multiple uses of irrigation supply

To this list of positive benefits, there are also certain adverse effects. Among the largest negative impacts are those related to social consequences associated with migration and resettlement of communities located on the site of the dam's location or its proximities (Tilt, Braun, & He, 2009) [4]. As a result, there are also changes in employment and opportunities for income generation, alteration of access to land and sometimes to water resources, among others. Another impact was emphasized by Duflo and Pande (2007), who indicate that although positive impacts occur downstream of dams, at the same time negative upstream impacts are manifested, as the worsening of poverty levels.

Other negative impacts manifest at the environmental level. Irrigation causes water table depletion and reductions in water quality (Scanlon, Jolly, Sophocleous, & Zhang, 2007), adverse impacts on human health (Srinivasan & Reddy, 2009). Agriculture is a source of negative impacts as well, by altering cropping patterns with the subsequent increase in salinity and waterlogging of arable land (Duflo & Pande, 2007).

Thus, in the international area issues as the distribution of the costs and benefits of large dams across population groups, and the extent to which the rural poor have benefited, are subjects that remain widely debated. Despite this concerns in Chile, the assessment of large irrigation infrastructure projects is based on direct benefits or impacts, such as those pointed out by Smith (2004), but not on potential adverse effects, which would require additional resources for their estimation. Even though externalities are mentioned in the process evaluation, they are not quantified and added in the calculations of profitability indices, as indicated in point 2.2. The rationale for infrastructure projects is to encourage a productive transformation in agriculture by providing secure access to water for irrigation, allowing changes in crop patterns consistent with a modern agricultural sector. Irrigation security of 85% allows to farmers for making significant investments as well as minimizing production risks and uncertainty (INTELIS, 2012; MIDESO, 2016). On the other hand, a certain existence of rural poverty could also be explained in part by the lack of water for irrigation, which

[4] (Duflo & Pande, 2007) señalan que más de 40 millones de personas han sido desplazadas en el mundo a casia de presas.

would justify an intervention aimed at improving productivity, determining increases in income and improvements in small farmer's well-being.

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2.4. Indicators

An indicator is an instrument that provides information on the achievement level reached by a task, project or program, and can cover either quantitative or qualitative aspect of this accomplishment (Ortegón et al., 2005). It is an expression that establishes a relationship between two or more variables, which compared to recent periods, products (goods or services) or a goal, allows to evaluate performance.

In the planning and formulation of projects, the use of indicators is very useful. The Logic Framework Approach (LFA) provides an excellent methodological basis for constructing well-defined indicators (DFID, 2003, Ortegón et al., 2005). The LFA notes that to develop and select appropriate indicators, there are two important aspects to consider in defining them:

- The indicators should cover dimensions that are relevant to project management: Quantity, Quality, Time, Place and Social group;
- Indicators must meet the five characteristics of what is called a "SMART" indicator, i.e. Specific, Measurable, Achievable, Relevant and Time-bound.

2.5. Evaluation

Evaluation is a systematic assessment and reflection on the design, implementation, efficiency, effectiveness, processes, results (or impact) of an ongoing or completed project (Ortegón et al., 2005). UNPD (2009) adds that through the generation of 'evidence' and objective information, evaluations enable managers to make informed decisions and plan strategically. When evaluations effectively apply, they support program improvements, knowledge generation, and accountability.

One important thing to remark is that monitoring and evaluation are not the same actions. Monitoring is the process of periodic supervision over activities implementation, and it is a systematic procedure used to verify the efficiency and effectiveness of a project execution process

(DFID, 2003; Ortegón et al., 2005). On the other hand, Evaluation examines what has been achieved or the impact that an intervention has achieved.

It is possible to identify three types of evaluation, according to the time in which they perform and to the outcomes/results that the project is getting (Ortegón et al., 2005). Thus, there are:

Table 1. Types of evaluation and time evaluation

Evaluation	Description
Short-Term	It is carried out after the execution phase, analyzing variables such as costs, time and technical specifications (size, product, location, among others).
Mid-term	It is a complete and detailed study that analyzes and matches the performance of estimated and real results for relevant variables. This evaluation takes place once an initiative has reached its full regime, generally some years after a project finishes. Given this type of assessment, real results of the project are available.
Long-term	It seeks to determine what is the success degree, and what factors explain the results. In this type of evaluation, the most important are to determine if the project implied/caused a significant change in beneficiaries in some conditions considered as fundamental in the project formulation (e.g. income or health). Long-term results evaluation time is variable according to the type of project, however, for irrigation projects, an appropriate period would be five and ten years later of project operation.

Source: Adapted from Ortegón et al. (2005).

3. Proposal of Indicators for Irrigation Projects

3.1. Large infrastructure projects and Logic Framework Approach

The previous chapters gave a brief description of the impacts of irrigation projects, the Chilean investment system where the construction of these types of projects insert, as well as some notions about indicators and evaluation. Regarding indicators as well as evaluation is based on the logical framework methodology (LFA), since in Chile during planning and design process LFA is applied. Each irrigation project is conceived through the method of the problem tree, which allows determining which is the problem to solve, the causes and their consequences. There is a direct relationship between the Problem Tree and the LFA, as well as the determination of impacts and the development of indicators, either for monitoring and evaluation as Figure 1 shows (for a standard problem tree of irrigation projects see Append 2). The consequences correspond to the impacts or goals to be achieved by the project.

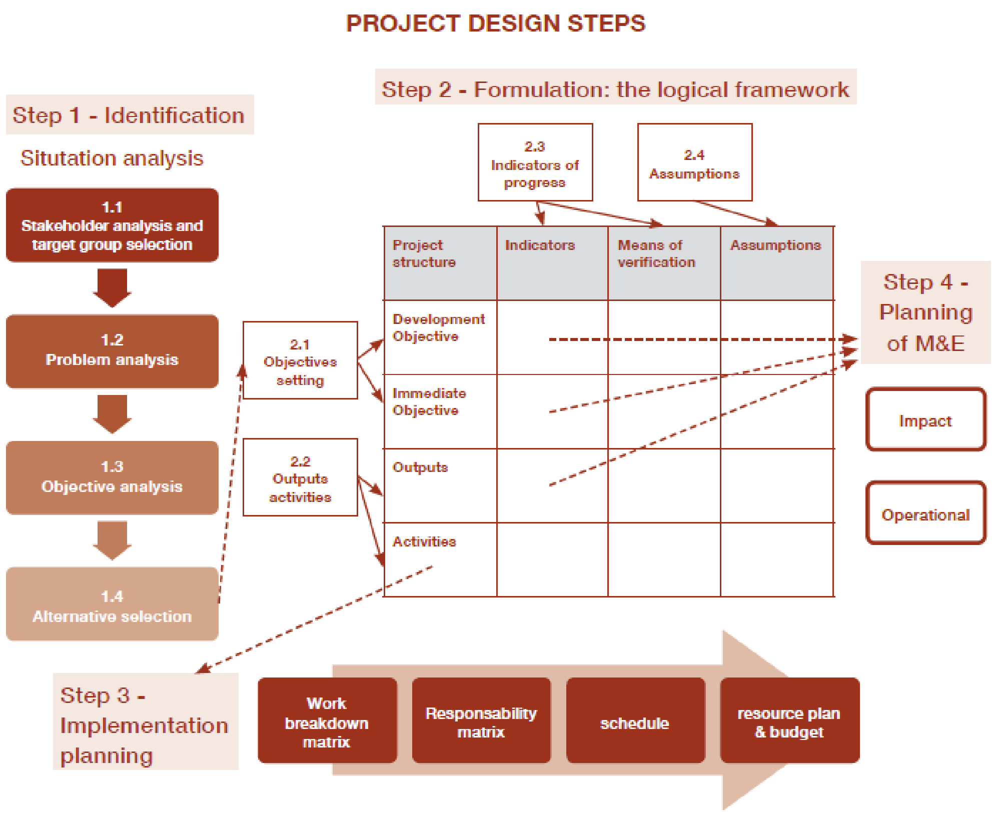

Figure 1. Relationship between Problem Tree and LFA, indicators, and Evaluation

3.2. Impact Indicators for Large Infrastructure Projects of Irrigation in Chile

Chapter 2.3 a series of impacts, both positive and negative, described in the literature, and which have supported both, its promoters and detractors, of this type of project was showed. According to this, and contextualizing it to the Chilean context, these impacts are cluster into five main dimensions, namely:

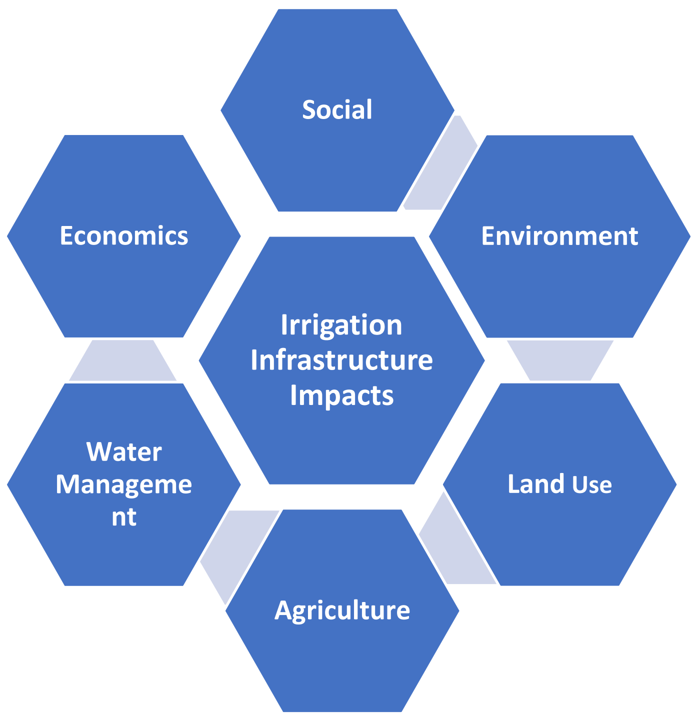

Figure 3. Impact Dimensions of an irrigation infrastructure project

From each of these dimensions, it is possible first to describe a series of specific implications, to later elaborate a set of useful indicators either for monitoring or a subsequent evaluation. The following table presents the potential impacts for each of the already mentioned dimensions, based on the literature review and Chilean irrigation projects. Thus, each impact includes:

- Dimension: Social, Economic, Agriculture, Water Management and Environmental
- Name: Corresponds to the name of the indicator
- Definition: A brief reference on what the indicator means

- Type of impact: Impact has been defined as positive (+), negative (-) or uncertain (U). A positive impact corresponds to whether the presence of the dam encourages or contributes positively in the area, Negative, otherwise. For those impacts that there is no certainty about its impact, it has been pointed out as uncertain.
- Source of information: It corresponds from where the data source for the estimation comes from.

i) Defining Indicators

Table 2. Main impacts/effects caused by large infrastructure projects of irrigation

Dimension	Impact Name	Definition/Description	Expected Impact	Source of Information /Verification	Type of Source
Social	Schooling (S)	Variation in the years of schooling of the population living in the reservoir's area of influence	+	National Census/CASEN Survey	Secondary
	Human Development (HDI)	Indicator of the average achievement achieved in the fundamental dimensions of human development, namely, health, knowledge and to enjoy a decent standard of living	+	PNUD-MDS	Secondary
	Migration (M)	Rate of immigration and emigration in the reservoir´s zone of influence	U	INE	Secondary
	Resettlement (R)	N° of Households relocated due to flooding area (upstream)	-	DOH	Secondary
	Poverty (P)	HH proportion under poverty line the reservoir influence area	+	CASEN Survey	Secondary
	Household Income (HHI)	Average variation in the autonomous family income of HH	+	CASEN Survey	Secondary
	Food Security (FS)	Access to enough food for an active, healthy life in the area	+	FAO	Secondary
Economic	Unemployment (UR)	Change in unemployment rate during and after project´s construction	U	INE	Secondary
	Water Rights (WRV)	Change in water rights value due to reduction of uncertainty	+	Real State Agency/ DGA	Secondary
	Water Market Activity (WMD)	Changes in water rights transactions due to reduction of uncertainty in the reservoir area	+	Real State Agency/ DGA	Secondary
	Farmers/Growers Investments (I)	N° and amount of investments in irrigation carry out by farmers (implementation of efficient systems) and water user associations (WUA) (e.g. waterproofing)	+	Farmers Survey/ JoV	Secondary/ Primary
	Land in Agricultural Use (TLAU)	Changes in the total area under agricultural production	+	Agricultural Chilean Census[5]	Secondary/ Primary

[5] The Chilean Agricultural Census is conducted every 10 years. The last official information dates from 2007.

Dimension	Impact Name	Definition/Description	Expected Impact	Source of Information /Verification	Type of Source
Agricultural production	Main crops cultivated (MCCA)	Changes in the main crops total cultivated area	+	Agricultural Chilean Census	Secondary/ Primary
	Agricultural Production Value	Changes in agricultural production value	+	Agricultural Chilean Census/Farmers Survey	Secondary/Pri mary
	Agricultural productivity	Change in land productivity use in agricultural farms Yield per hectare of land, by type of farmer (kg/ha)		Farmers Survey	Primary
	Irrigation rate	Changes in the irrigation rate or water sheet applied per year (m^3/ha/year)	+	Farmers Survey	Primary
	Water Productivity	Changes in the level of productive efficiency of water use (production kilos per volume unit of water, Kg/m^3/year)	+	Farmers Survey	Primary
	Sales and Costs of farming production	Change in production, sales, and reduction in costs in agricultural properties with water rights of the reservoir.	+	Agricultural Chilean Census/Farmers Survey	Secondary/ Primary
	Exportation	Changes in export levels in the area of influence of the reservoir	+	Farmers Survey	Primary
Land Use	Area under irrigation	Variation in total area under irrigation (ha)	+	Agricultural Chilean Census/Farmers Survey	Secondary/ Primary
	Irrigation Technology	Farms changes in infrastructure and irrigation technology in farms	+/U	Agricultural Chilean Census/Farmers Survey	Secondary/ Primary
	Irrigation area efficient systems	Changes in irrigation area applying efficient systems	+/U	Agricultural Chilean Census/Farmers Survey	Secondary/ Primary
	Value of Agricultural Land	Changes in farmland value in the influence reservoir´s zone ($/ha).	+	Survey, Real State Agency	Secondary/ Primary
	Land using efficient irrigation system	Total irrigation area using efficient irrigation systems (e.g. drop, sprinkler)	+	Agricultural Chilean Census/Farmers Survey	Secondary/ Primary
	Land tenure (LT)	Changes in patterns of distribution of land tenure structure (e.g. proportion of land in the hands of small or large farms)	U	Agricultural Chilean Census/ Real State Agency	Secondary/ Primary
Water Management	Water delivery security	Changes in water supply reliability for irrigation due to water storage by the reservoir	+	WUA	Primary
	Water conveying efficiency	Changes in time of water conveying efficiency due to improvements in delivery channels impermeability	+	WUA	Primary

Dimension	Impact Name	Definition/Description	Expected Impact	Source of Information /Verification	Type of Source
	Water cost (Water rights delivery)	Variation in time of water usage cost ($/m3) paid by farmers/growers	-	WUA	Primary
	Annual Operation Cost (Dam)	Variation in time of dam operation and maintenance cost ($/m^3)	-	DOH/WUA	Secondary/ Primary
Environmental [6]	Fish	A dam affects fish migration, and in some cases and with some species completely separate spawning habitats from rearing habitats. Large reservoirs have led to the extinction of many fish and aquatic species	-	¿??	
	Sedimentation	A dam traps sediments, which are critical for maintaining physical processes and habitats downstream. Also it holds back sediments that would naturally replenish downstream ecosystems.	-	¿???	
	Land/Forest	Changes in forest area both in the reservoir area and in irrigation zones (after dam)	-	CONAF, SAG	Secondary
	Water quality	Changes in the parameters (physical, chemical, biological) that indicate water quality for a river	-	DGA, WUA	Secondary/Pri mary
	Water flow	Alteration of flow rates, reducing the flow in winter and abruptly encrusting it in the months of greater agricultural demand (and changes to the associated natural environment).	-	DGA, WUA	Secondary/Pri mary

[6] Based on https://www.internationalrivers.org/environmental-impacts-of-dams

ii) Indicators

It was pointed out already that CNR does not carry out monitoring and evaluation work on the possible effects of large irrigation works once the project is in operation. Therefore, the aim of this proposal is to set a series of indicators in several dimensions that allow getting a general idea of these impacts for any irrigation intervened area. Thus, it will be possible to get a measurement of the evolution of a particular initiative, as well as to allow for comparability among projects. These indicators could lead to the development of a national monitoring and evaluation system for large irrigation projects.

Regarding the proposed indicators, it is necessary to point out some methodological details. First, the development of indicators has followed the logic of the LFA above. Using LFA provides some advantages, such as the knowledge of this methodology by professionals of institutions in the irrigation arena, and therefore a faster and easier internalization of what an indicator is and looks for. That situation facilitates understanding, data collection, and as a result monitoring and evaluation efforts. Moreover, some proposed indicators considered in the planning and assessment process of each project. Hence, these indicators effectively measured once the reservoir is built will allow evaluating the level of accuracy of the estimates made, giving feedback to the process. As was mentioned above, various indicators proposed arise from irrigation projects planning, which mainly pursues productive or economic purposes, rather than those that seek to highlight adverse effects, such as those related to the environment.

Finally, but not least, there is the one related to the sources of information. Although all the indicators are possible to measure through primary sources (surveys), this proposal privileges to those that it is feasible to obtain the information of secondary sources. Although this information is not unique to each project, due to its free access as methodological collection rigor by other institutions, it is considered a good starting point for estimating the trends of certain populations or areas.

Thus, this proposal of indicators is according to the information needs of the LFA. In this way, each indicator in the table shows the following particulars:

- **Indicator**: Corresponds to the name of the indicator
- **Evaluation term**: It allows to recognize if the indicator is of Short, Medium or Long Term

- **Estimation Formula**: It corresponds to an explicit definition of the indicator in a mathematical expression
- **Measuring area**: Geographical area in which the indicator is measured/estimated
- **Frequency**: How often an indicator should be measured.
- **Source of data**: From where comes from the data to estimate an indicator.
- **Type of Data**: Whether is a primary or secondary source of data
- **Responsible**: Agency in charge of source of data

At the operational level, these indicators can be recorded in a database, which will be updated according to the need for information for the estimation of a specific indicator. Today, there is availability of several software that allow the gathering of information as well as the automatic calculation of the indicators through programming routines (e.g. Stata, Excel), without having to rewrite each time the calculation equation, graphs or the information that is required.

Hence, the following are the indicators that, given the Chilean context, are considered more important to measure. These correspond to all dimensions. Append 3 adds a list of possible additional indicators (but not developed in detail).

Dimension	Indicator (s)		Evaluation Term	Formula	Frequency
Social	Migration	Migration Index (MI)	S-M-L term	*IM= (N° of people currently living in the influence dam area whom last 5 years were living in another Chilean county)/(N° of people currently residing in the influence dam area)*100*	Before, during and after reservoir construction
	Resettlement	HH relocated by the project (RHH)	Short-term	*N°HH of resettled House Holds (Summation)*	Before starting project´s tender
		Variation on RHH	Short-term	HH estimated: Relocated HH estimated by the project $\frac{(N°\ HH\ resettled - N°\ HH\ estimated)}{N°\ HH\ \ estimated} * 100$	Before starting project´s tender
	Poverty rate (PR)	Poverty rate (PR) Variation in Poverty Rate	Long-term	$Poverty_i = \frac{HH\ under\ poverty\ line_i}{Total\ of\ HH}$ Variation: $Poverty_i - Poverty_{2011}$	2 years
	Autonomous Income	Autonomous Income	Long term	$Autonomus\ Average\ Income$ $\frac{(Autonomus\ Average\ Income_t - Autonomus\ Average\ income\ _{t-n})}{Autonomus\ Average\ income\ _{t-n}}$	2 years
Economic	Unemployment Rate (UR)	Unemployment Quarterly Rate (UR)	Mid-Long term	$UR_i = \frac{Total\ of\ unemployed\ people\ in\ quarter\ _i}{Total\ of\ people\ economically\ active\ in\ quarter\ _i}$ Variation: $UR_i - UR_{i-1}$	Quarterly
	Farmers investments	Farmers accessing irrigation	Mid-Long Term	FAS: Farmers accessing subsidies in the last 5 years	

Dimension	Indicator (s)		Evaluation Term	Formula	Frequency
		subsidies (SFAS)		$FAS_{it} = \frac{\text{FAS}_{it}}{\text{Total Farmers}_{it}}$ Variation $Farmers_{it} - Farmers_{it-n}$ Where i =1 if small farmer; 2 Otherwise	Annually
		WUA accessing to irrigation subsidies (WUAS)	Mid-Long Term	Average of WUA accessing subsidies in the last 5 years $WUAS_{it} = \frac{N° \; of \; WUA \; accessing \; to \; subsidies \; of \; irrigation_{it}}{Baseline_t}$ Variation $WUA_t - WUA_{t-n}$	Annually
Agricultural	Land in Agricultural Use	Total Land in Agricultural Use (TLAU)	Long Term	$TLAU_t$ (ha) $= \sum_{i=1}^{n} Crop \; Area_{\; it}$ Variation TLAU (%) $\frac{(TLAU_t - TLAU_{t-n})}{TLAU_{t-n}}$	5 - 10 years
	Area of Main Crops (Crop)	Area of Main Crops (Crop)	Long Term	$Crop_{it}$= Total area for agricultural production in year t (ha Variation in Area for Crop i $Crop_{it} = \frac{(Ha \; Crop_{i\,t} - Ha \; Crop_{i\,t-n})}{Ha \; Crop_{i\,t-n}}$	5 -10 years
	Agricultural productivity (Yield)	Yield of land(kg/ha), by crop and farmer type	Long Term	Average Variation in Yield for Crop i, year t $Yield \; Crop_{it} = \frac{(kgha^{-1}Crop_{i\,t} - kgha^{-1}Crop_{i\,t-n})}{kgha^{-1}Crop_{i\,t-n}}$	3 - 5 years

Dimension	Indicator (s)		Evaluation Term	Formula	Frequency
	Agricultural Production Value (APV)	Measurement of change in the average agricultural value per farmer type	Long Term	P_i: Price of crop i ($/kg) Y_i: Yielcrop i ha_i: N° of hectares of crop i $$APV_t(\$) = \sum_{i=1}^{n} P_i * Y_i * ha_i$$	3 - 5 years
	Irrigation rate (IR)	Irrigation rate (IR)	Mid Term	$IR_{it}\ (m^3/ha\ /year) = Volume\ of\ water\ consumed\ by\ crop\ _{it}$	3 - 5 years
	Water Productivity (WY)	Water Productivity (WY)	Long Term	$$WY_{it}(kg/m^3) = \frac{YieldCrop_{it}}{IR_{it}}$$	3 - 5 years
Land Use	Area Under Irrigation (AUI)	Area Under Irrigation (AUI)	Long Term	$IrrigatedCrop_i$ (ha)= Area under irrigation for Crop i $$AUI_t(ha) = \sum_{i}^{n} IrrigatedCrop_{it}$$	5 -10 years
	Value of Agricultural Land (VAL)	Value of Agricultural Land (VAL)	Short-Long Term	$VAL_t(\$/ha) = Irrigated\ land\ value_t - Rainfed\ land\ value\ _t$	3 – 5 years
	Area using Efficient Systems (AES)	Area using Efficient Systems (AES)	Long Term	*EfficientCrop$_I$ (ha)= Area under irrigation for Crop i using efficient systems (drip, sprinklers)*[7]	5-10 years

[7] For the Chilean Agricultural Census, efficient systems are named micro-irrigation.

Dimension	Indicator (s)		Evaluation Term	Formula	Frequency
	Land Tenure (LT)	Small Farmers Tenure (SFT) Proportion of SFT in year t (%SFT)	Long Term	For N° small farmers[8] $SFT = \sum_{i}^{n} Agricultural\ units\ corresponding\ to\ SF$ $\%SFT_t = {SFT_t}/{\sum_{j=1}^{m} Agricultural\ units}$ For SF are SFTA $SFTA = \sum Agricultural\ Area\ for\ SF$ $\%SFTA_t = {SFTA_t}/{Total\ Agricultural\ Area}$	3 – 5 years
Water Management	Delivery guarantee for irrigation water	Effective water security (monthly) (WDS) Effective water security (annual) (AWDS)	Long -term	Monthly: $WDS_i = \frac{Total\ amount\ of\ water\ delivered\ in\ month_i}{Total\ amount\ of\ water\ demanded\ in\ month_i}$ Where i=1 to 12 (month with 1= September) WDS = 1, there is no failure Annually Effective water security[9]: $AWDS_t = \frac{N°\ of\ years\ with\ delivery\ failure_t}{N°\ of\ years\ since\ reservoir\ operation_t}$ 1 (no failure)	Annually

[8] In Chile, a small farmer corresponds to natural person who exploits an area not exceeding 12 Hectares of Basic Irrigation, whose assets do not exceed the equivalent of 3,500 UF, that their income comes mainly from the farm (>50%), and that works directly the land, whatever its tenure regime (http://www.indap.gob.cl/indap/qu%C3%A9-es-indap).

[9] Failure year: Hydrologic year in which the monthly water demand is satisfied with less of 85% for any month, or if for any month of the year satisfaction rounds 85-90% for two consecutive months.

Dimension	Indicator (s)		Evaluation Term	Formula	Frequency
Environmental	Ecological Flow	Ecological Deviation (EFD)	S-M-L term	EFD_{it} = Environmental Flow month i, year t $EF(EIA)_i$= Environmental Flow for month i set in EIA $EFD_{it} = EF_{it} - EF(EIA)_i$	Monthly
	Water Quality	Water Quality Parameter Deviation (WQPD)	S-M-L term	WQD= Water quality deviation parameter $_i$ montj $_j$ year $_t$ WQPD= Concentration of Parameter $_i$ month $_j$ year $_t$ WQP(norm)= Parameter concentration $_i$ regarding norm of water quality $WQD_{ijt} = WQPD_{ijt} - WQP_i$	Monthly

4. Application

The idea of this section is to check the feasibility of applying some proposed indicators, especially those related to the agricultural dimension of irrigation projects. An application for some variables on the Paloma System[10], Region of Coquimbo, for some recommended indicators in the "Agriculture" dimension, such as Area under cultivation, Changes in cropping patterns, Irrigation Security, and Efficiency of irrigation systems is made. About the area under cultivation, before the construction of the reservoir was 28,500 ha. The planning of the dam proposed an intensification of water use, but given the demands of the new crops, the estimated area was 20,000 ha. Contrary to what is estimated, the area to 2007 is about 50,000 ha.

In the case of the crop pattern, the figure shows a clear growth of pastures, orchards, and vineyards, while cereals (rainfed cultivation) decreased dramatically. As for irrigation safety, this increased to double (40% to 85%), and irrigation systems changed from inefficient systems (nearly 100% irrigated with flooding) to 30% drip in 97 and practically 60% drip in 2007, showing a clear intensification of agriculture, given the country's export approach.

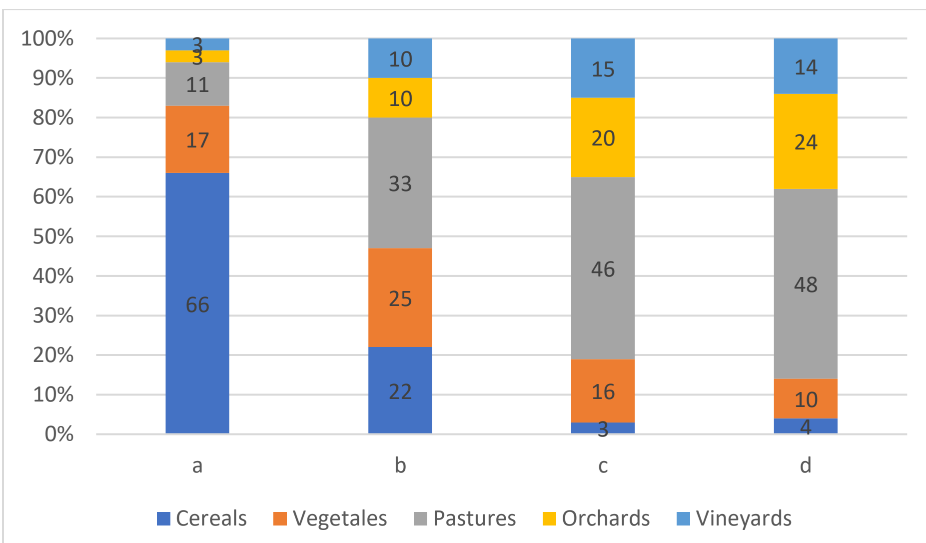

Figure Xx. Crop patterns in the lower Limarí Basin: a) when the reservoir was planned b) as expected to evolve in the future when the reservoir was designed; b) Agricultural census of 1997; d) Agricultural census of 2007.

[10] Paloma System is a reservoir network formed by three reservoirs, namely: Cogotí, Recoleta and Paloma.

Another example of application is the Santa Juana Reservoir, Atacama region, a reservoir that was part of the last major reservoir construction program during the 90-2000[11]. Table XX shows the differences in crop area for three moments: a) the projected and b) Agricultural Census of 2007. The Table shows a sharp increment of Orchards (Olives, Avocado, and Table grape), and a remarkable decline for cereals, vegetables, and pastures. Likewise, to Paloma Systems, agriculture turned to exportations, in which orchards are very important.

Table XX

Crops	Farm Land Projection 1991	Census 2007	Difference (ha)	Var %
Orchards	2,223	3,928	1,705	77%
Vineyards	1,800	447	-1,353	-75%
Vegetables	1,031	1,330	299	29%
Cereals	1,324	256	-1,068	-81%
Pastures	4,451	2,024	-2,427	-55%
Other	0	353	353	
Total	10,829	8,338	-2,491	-23%

For the other indicator that was found information is for the productivity of the three top fruit trees. For avocado, the productivity had a slight increase (11 to 12.5 ton/ha), while for table grapes a substantial increase (14 to 23 ton/ha) was found. Regarding irrigation safety, it went from 35% to that required by design, 85%.

[11] Based on MIDESO (2012). "Estudio ex post de corto y mediano plazo "Embalse Santa Juana", III Región de Atacama."

5. Comments and Conclusions

For the proposal of indicators and the application made in the previous chapter, it is possible to make some observations. About the use of secondary sources, and as previously noted, the areas under study do not fit perfectly into the administrative boundaries on which information is available, so sometimes the results obtained will not be such a precise estimate of what may be happening in the area of influence of the reservoir. Also, the frequency in the provision of some statistics every ten years, such as those generated by the National Agricultural Census, creates difficulty in establishing trends with sufficient data, especially to see agricultural impacts. Another point to note is that no baseline or target goal are included for indicators. This is because both are project specific, and mainly because as there is no evaluation to date, there is no need to set goals.

However, despite this lack of accuracy, the use of this type of data has certain advantages, especially in the context of public institutions. In the first place, this information presents a minimum expenditure, both monetary and time. Another important aspect relates to the comparability between initiatives being implemented simultaneously, as well as to compare (or estimate) the results of a vast number of projects. From this data, it is possible to make comparisons before/after or establish trend lines. This is exemplified for some variables for the Paloma System and the Santa Juana Reservoir. However, these applications undress another possible failure, access to information, which is nevertheless possible to remedy within an institution.

A future step to this, if there is interest in a better understanding of the effects of irrigation works, it is applying this same set of indicators to places where there are no irrigation projects, being able to compare before/after situations and for different areas at the same time. In this way, it would be isolating certain effects that could be supposed to be caused by a reservoir, but in practice, it is not. To do it technically correct, a regression method of impact evaluation (Differences in Differences) could be used via a panel data estimation (fixed effect), looking for the effect of, for instance, the influence of a reservoir on some variable of interest (e.g. agricultural productivity, poverty level, etc.) could be verified, controlling by time-invariant unobservables (e.g. average temperature) and not observed variables, among counties and regions. Also, it will be required include some controlling by relevant socioeconomic variables of control, such as income level, average schooling level, etc.

Finally, it is important to point out that this set of indicators will make it possible to have a general image, in principle, on the development of areas prioritized by the state and on the application of public management instruments. The drought with which it has had to deal with the agricultural production area, especially small farmers, as well as the alarming projections of the climate change will become increasingly important the use of quantitative information for farmers as well as professionals, extension agents, and authorities, for which this proposal represents an initial stage.

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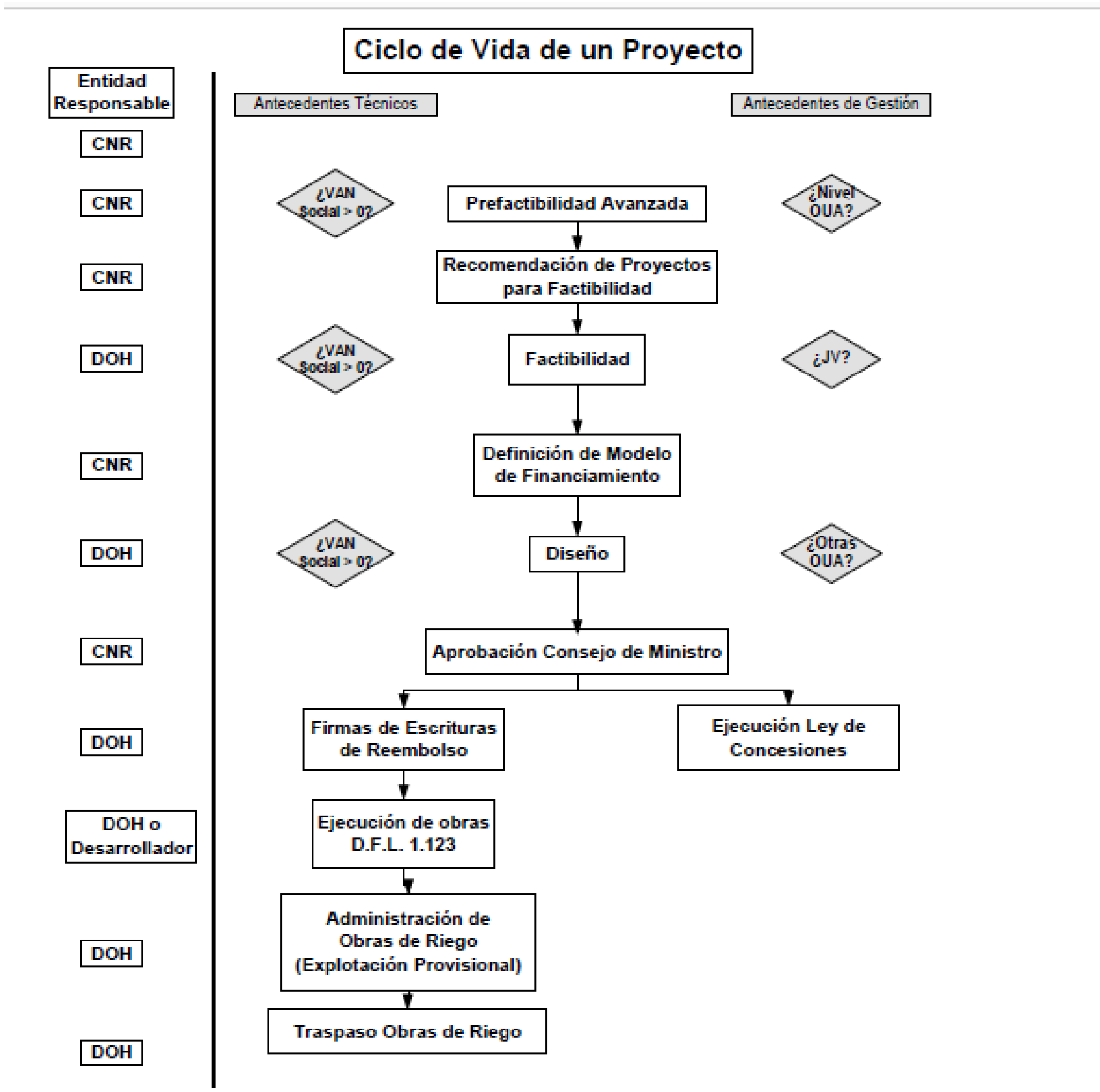
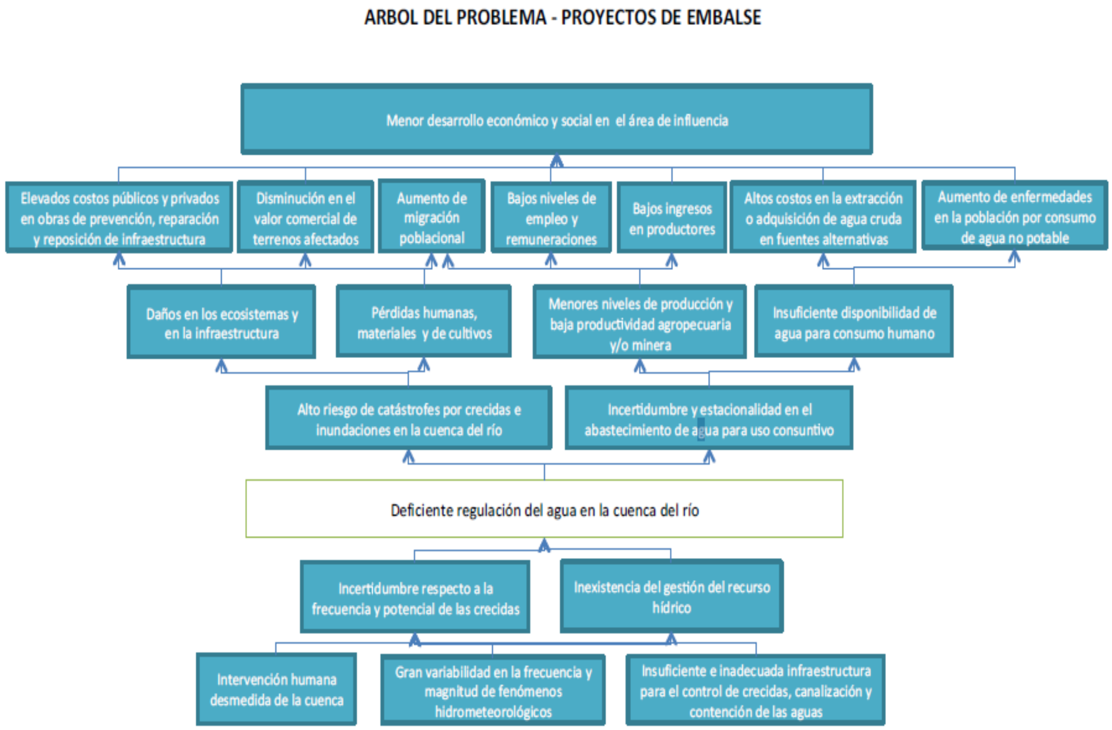
Append 1. Life Cycle of a Large Irrigation Project



Append 2. Problem Tree of a Large Infrastructure Project



Append 3. Additional Indicators

Dimension	Indicator	Source of Information
Social	Schooling	INE, CASEN
	Human Development Index	UNDP
	Resettlement Cost	DOH, CNR
	Changes in water rights transactions due to reduction of uncertainty in the reservoir area	DGA
	Degree of isolation of localities in reservoir influence area of the	MOP
Water Management	Water user satisfaction for water delivery	WUA, JoV
Economic	Government Emergency Expenditure Aid	MINAGRI, CNR
	Changes in exportation levels in the area of influence of the reservoir	MINAGRI, DIRECON
	Changes in production, sales, and reduction in costs in agricultural properties with water rights of the reservoir	MINAGRI, ODEPA
	Composition of agricultural products produced in the area	INDAP, CNR, ODEPA, MINAGRI
Environmental	Watershed index	DGA, CNR, MINAGRI
	Sustainability Index	DGA, CNR, MINAGRI,
	Changes on vulnerability level of river species	??
	Changes in forest area both in the reservoir area and in irrigation zones (after dam)	CONAF