IMPACT VALUATION OF THE LAS CRUCES HYDROELECTRIC PROJECT ON NATURAL AND SOCIAL CAPITAL

Full Report

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About Pixan'Ja

Pixan'Ja is a consulting agency active in the Mesoamerican region and the Caribbean. It seeks to transform outdated conservation practices into relevant conservation activities while facilitating their application through innovative tools and models, such as social and environmental economies and new market strategies. Pixan'Ja was co-created by Ángela Mojica and Ana Giro, both with nine years of experience working with civil society organizations, particularly on issues related to marine conservation. Their experience ranges from scientific diving and marine science to generating information for public policy and consulting for recent environmental legislation, including strategy design, analysis, and development of models. Their experience includes effective management of natural protected areas, integration of economics and finance in conservation strategy, development of new methodologies, creation of local capacity and communication strategies, and securing commitments from key stakeholders. Their clients include MARFund, the Mexican Fund for the Conservation of Nature, Conservation Strategy Fund, the Private Institute for Climate Change Research, and the World Bank, among others.

About Valuing Nature

Valuing Nature's mission is to help organizations integrate the value of nature and society into decision-making, by providing innovative methods, data, and experience. Samuel Vionnet founded Valuing Nature in 2015. He is an independent consultant with eight years of experience in sustainability and water resource management. Before founding his organization, Samuel worked for six years with Quantis International supporting organizations worldwide on their strategies, using sustainability metrics. Valuing Nature works primarily with the private sector, advising multinational companies around the world on issues that include sustainability metrics, water stewardship, risk assessment, supply-chain management, sustainability strategy, and natural and social capital accounting. His clients include Nestlé, Novartis, Olam, Natura, Nespresso, Samsung, Natura and Firmenich, among others.

Collaborators:

Delimitation of the study area, maps elaboration, access to demographic information, and development of hydraulic models for the San Pedro River watershed were made possible by the technical support of Manuel Llano (Cartocrítica - Mexico) and Marc Fasel (Geoinsight - Switzerland).

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Content

Abbreviations and Acronyms

AIDA	International Association for Environmental Defense
ARA	Active River Area
BDP	Billions of Pesos
BUSD	Billions of US Dollars
CAD	Canadian Dollars
CBD	Convention on Biological Diversity
CFE	Federal Commission of Electricity
CH_4	Methane
CONABIO	National Commission for the Knowledge and Use of Biodiversity
CONAGUA	National Water Commission
CONANP	National Commission for Natural Protected Areas
CO_2	Carbon Dioxide
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FONNOR	Northeast Fund
FTE	Full Time Equivalent
GHG	Greenhouse Gases
GWh	Gigawatt Hour
Ha	Hectare
hm^3	Cubic Hectometer
HEC-RAS	Hydrologic Engineering Center River Analysis System
HP	Hydroelectric Project
INE	National Electoral Institute
INECC	National Institute of Ecology and Climate Change
INEGI	National Institute of Statistics and Geography
IRENA	International Renewable Energy Agency
IISD	International Institute for Sustainable Development
kWh	Kilowatt Hour
m^3/s	Cubic Meter per Second
MDP	Millions of Pesos
MEA	Millennium Ecosystem Assessment
MUSD	Millions of US Dollars
MXN	Mexican Pesos
MWh	Megawatt Hour
NCP	Natural Capital Protocol
NGO	Non-governmental Organization
PA	Natural Protected Area
PCR	Regime-Change Dam
PPP	Purchasing Power Parity
POIS	Electric Sector Program for Construction and Investment
PwC	Price Waterhouse and Cooper
RBMN	Marismas Nacionales Biosphere Reserve
SCP	Social Capital Protocol
ES	Ecosystem Services

SEGOB	Ministry of the Interior
SEMARNAT	Ministry of the Environment, Natural Resources, and Fisheries
SENER	Ministry of Energy
SuMar	SuMar Voces por la Naturaleza, A.C.
t	Metric Ton
TNC	The Nature Conservancy
USD	US Dollars
WBCSD	World Business Council for Sustainable Development
WTA	Willingness to accept
WTP	Willingness to pay
WWF	World Wildlife Fund
-eq	Equivalent

Translator's note: All acronyms refer to the corresponding terms and titles in Spanish, unless an officially recognized equivalent exists in English, in which case, the latter is used.

Executive summary

Context

Las Cruces hydroelectric project (240MW of power installed for an announced construction cost of 639 million USD (MUSD)) is a project proposed by the Federal Commission of Electricity (CFE) of Mexico, which aims to cover the regional increased demand for electricity, while supporting the country's commitment to reduce its greenhouse gas emissions (GHGs), in line with its commitment to the Paris agreement.

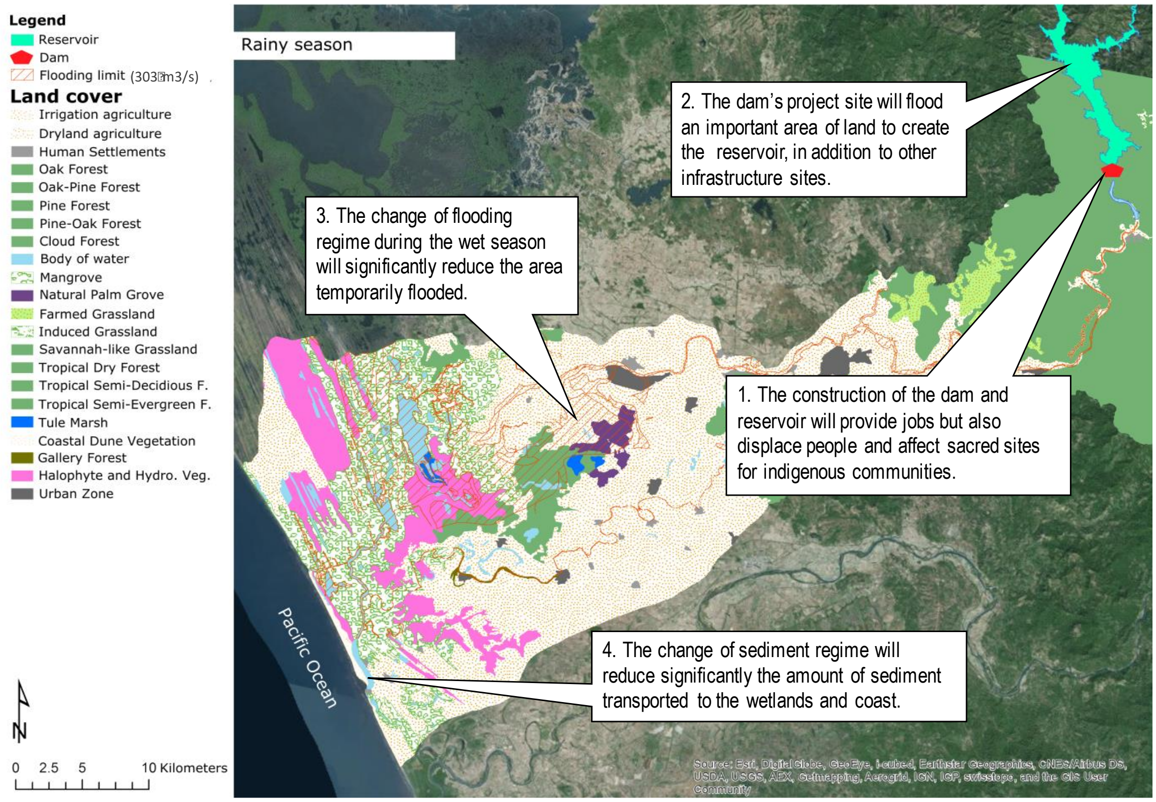
The project is located on the San Pedro Mezquital river, in the state of Nayarit, on the west coast of Mexico. Downstream of the dam is one of the most important natural protected areas called Marismas Nacionales, which hosts the largest mangrove reservation in Mexico (200'000 ha). Its existence and biodiversity relies on the flooding and sediment regime provided by the San Pedro river. Wetlands and mangroves provide a wide range of ecosystem services to communities (e.g., nurseries for species with ecological and commercial importance, water filtration and regulation, protection against coastal erosion and climatic extreme events, among others), and also have one of the highest capacities to sequester and store carbon. Wetlands and mangroves' ecosystem services value is on average around 25'000 USD/ha and can be above 100'000 USD/ha in specific cases.

Las Cruces project has been controversial since its proposal and initial approval by the government in 2014 (environmental and construction permits, as well as permission to use water for its operation), as different stakeholders might be impacted by its construction, including population displacement, flooding of sacred sites for local indigenous communities, and changes of flooding and sediment regimes which support local fisheries and agriculture activities. Nonetheless, the project might support the local economic development through employment generation, in particular during the construction period of the dam. The most recent news (July 2017) indicate the project it's been stopped by a judge failing in favor of the Náyeri and Wixárika indigenous communities and against the Secretary of the Environment and Natural Resources (SEMARNAT), the National Commission for Water (CONAGUA) and the CFE for granting construction permits to develop Las Cruces hydroelectric project, since it violates the human rights of Nayarit indigenous communities.

Study objective and methodology

In this context, Fondo Mexicano para la Conservación de la Naturaleza, A.C. (FMCN) commissioned this study to assess whether Las Cruces hydroelectric project will deliver societal benefit above its negative impact, through a cost-benefit analysis. It is well known that big infrastructure projects, mega dams particularly, are complex systems generating both costs and benefits to the society. Assessing and measuring them is key to support decision making of authorities and inform stakeholders and civil society.

This study relies on the natural and social capital protocols (NCP, 2016; SCP, 2017). We built an assessment framework based on identified impact pathways, using the latest impact valuation methods. There are four impact drivers caused by Las Cruces project: 1) direct impact from the project (reservoir, dam, etc.), 2) social changes (employment, displaced population, etc.), and changes in the 3) flooding and 4) sediment regime of the river. The figure below illustrates the watershed under the study, from the reservoir and dam, to the Pacific Ocean with a classification of land cover.



Each of those drivers were developed further into outcomes that are listed in the figure below. The major changes observed are:

- The creation of 5'000 direct jobs and potentially 5'000 other indirect jobs during the construction of the project
- The flooding of 14 sacred sites
- The displacement of 66 persons from the reservoir area
- The modification of 5'493 ha of terrestrial ecosystems to build the reservoir, two dams and other infrastructures/buildings
- A reduction of the river's average flow during the wet season leading to a reduction of flooding of 916 ha of agricultural land relying on the sediments brought by the water for its fertilization and of 2'257 ha of wetlands and mangroves that will disappear at the benefit of other terrestrial ecosystems.
- A reduction of sediment transported to the coast leading to an average of 23 ha per year of area lost to the sea, with an increased risk of impact from extreme events.

Output	Social changes	Project's impact	Flooding regime	Sediment regime
Outcomes	Displaced population Sacred sites Jobs *Tourism activity*	Land covered by reservoir Reservoir GHGs emissions Construction GHGs emissions	Carbon Fisheries Biodiversity/habitat Water quality Agriculture	Water quality Carbon Fisheries Biodiversity/habitat Extreme events Agriculture losses

Results

The results were developed using average estimates based on the best available data. A period of 25 years was used to assess the project impacts and discounted rates were not used, although discounted rates results are included in the main report. High and low estimates of key parameters used in the model were tested in a sensitivity analysis and are transparently reported in the table below. The results indicated that Las Cruces hydroelectric project would represent a net loss of 931 MUSD. The following figure shows detailed results for each of the four main impact pathways assessed in this analysis.

		Average estimates	**Low estimates**	**High estimates**	**Low estimates (relative change to mean)**	**High estimates (relative change to mean)**
		MUSD	**MUSD**	**MUSD**	**%**	**%**
Social impacts	Jobs	40	91	17	226%	43%
	Sacred sites	(6)	(4)	(19)	63%	313%
	Displaced population	(3)	(3)	(3)	100%	102%
Impact of project	Land covered by reservoir	(166)	(83)	(209)	50%	126%
	Reservoir's emissions	(103)	(21)	(385)	21%	374%
	Dam's construction carbon footprint	(10)	(4)	(25)	38%	256%
Flooding regime	Water quality	(2)	(1)	(2)	79%	121%
	Biodiversity/habitat	(2)	(1)	(2)	45%	155%
	Carbon storage and sequestration	(360)	(138)	(922)	38%	256%
	Fisheries	(2)	-	(1'693)	0%	69'444%
	Agriculture	(12)	(4)	(20)	33%	167%
Sediment regime	Water quality	(0)	(0)	(0)	81%	119%
	Biodiversity/habitat	(0)	(0)	(0)	45%	155%
	Carbon storage and sequestration	(17)	(7)	(45)	38%	256%
	Fisheries	(0)	-	(60)	0%	69'444%
	Agriculture	(4)	(4)	(4)	100%	100%
	Extreme events protection	(6)	(6)	(6)	100%	100%
Financial	Net results	(279)	299	(763)	-107%	273%
	Net value in millions of USD	**(930.8)**				

The most significant negative impacts arise from:

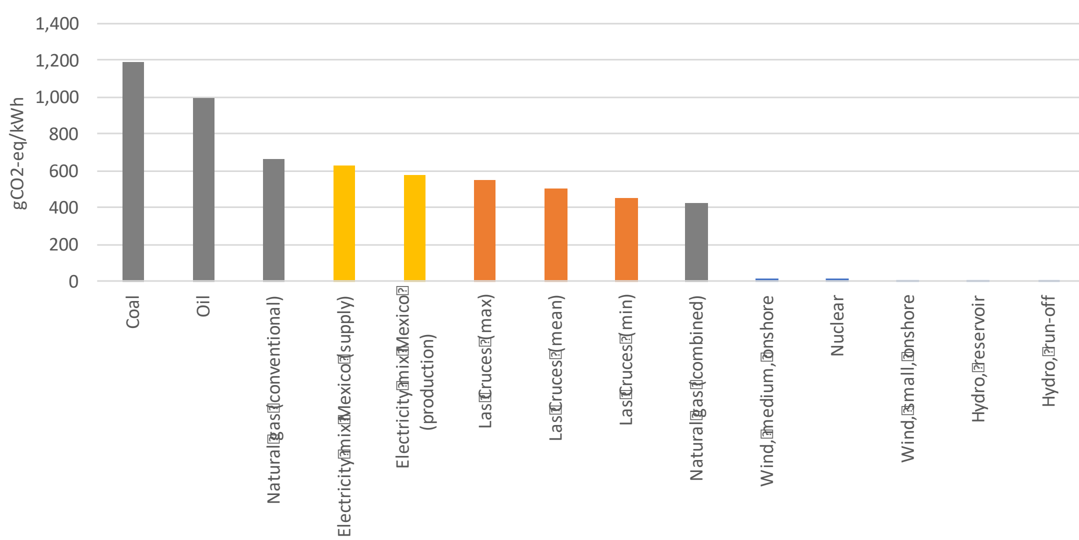
- The **land covered by the reservoir** and the related loss in ecosystem services (166 MUSD)
- The **GHGs from the reservoir** during its operation. It has been recently shown that this impact has been systematically under-estimated worldwide, in particular in tropical regions (103 MUSD)
- The **loss of wetland and mangroves area** due to the reduction of the flooding regime, and the related loss of carbon stored and sequestered (360 MUSD)
- The **financial losses** due to the imbalance between project costs and revenues from the sales of electricity (279 MUSD)

The variability of some parameters is high as it is difficult to anticipate the future in specific cases. For instance, the financial profitability of the project relies on the future electricity market price, as well as the control of construction costs. It has been shown that hydroelectric projects have overruns costs of 70% on average around the world. Additionally, the electricity market in Mexico was just started its liberalization leading to a reduction of electricity sales price from utilities. The prices were shown to drop by roughly 40% in the last year. The profitability of the project would require a price of approx. 55 USD/MWh, whereas the latest contracts were negotiated at 33 USD/MWh.

Some other parameters such as the social cost of carbon (SCC) can greatly vary, from a few tens of USD/tCO2-eq to more than 200 USD/tCO2-eq, thus the choice of SCC can influence the results significantly. Lastly, some parameters such as the GHGs from the reservoir as well as the value of fisheries per ha of mangroves/wetlands are also highly variable depending on the method used.

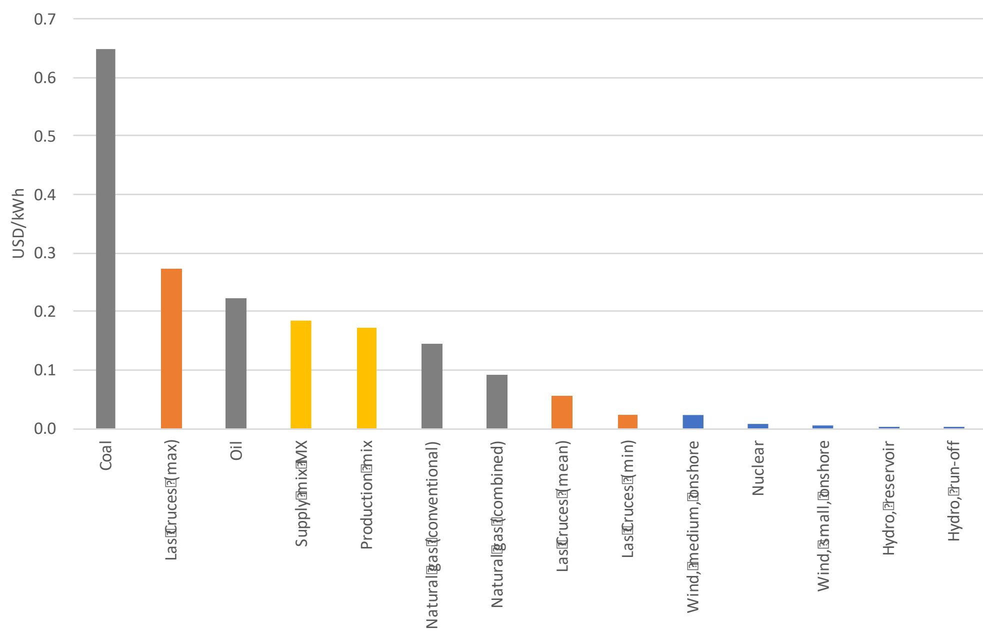
Benchmarking

We benchmarked the results obtained for Las Cruces project with other sources of electricity in Mexico, focusing first on GHGs. The figure below shows the project's average, low and high estimates results (orange bars), compared to other sources of electricity including the country mix (supply and production).



We observe that Las Cruces project has GHGs per kWh in the range of the Mexican electricity mix and above the most efficient natural gas thermal electricity plants. Las Cruces hydroelectric project was expected to reduce Mexico GHGs emissions by 304'807 tCO2-eq annually, but according to our calculations, a more accurate estimate indicates a reduction of 51'657 tCO2-eq or only 17% of the expected reduction.

We also compared the full natural capital costs of the same electricity sources described above and expressed the results in terms of USD costs per kWh. Those results exclude the financial results and jobs created as this data was not available for all data points.



This comparison shows that Las Cruces project, despite having the “renewable energy” label, is closer to non-renewable electricity sources than to real renewables ones. The higher estimates for Las Cruces even positioned it as impactful as oil-based electricity plants and well above the electricity mix of Mexico.

Conclusions

The results presented here are based on the best public knowledge and should be considered potential impacts rather than real impacts.

The analysis showed that the negative costs are greater than the benefit for Las Cruces Project, and despite the uncertainties highlighted by the sensitivity analysis, this conclusion remains the same. The results highlighted and quantified impacts that were not necessarily captured by the Mexican government, CFE or other stakeholders. Those issues are in particular the GHGs emissions from the dam, the loss of wetlands and mangroves areas due to the change of flooding regime and the land lost due to the project (from the flooding of the reservoir mostly but also from the coastal erosion to a lesser degree). The contextualization of the results using other sources of electricity for both GHGs emissions and overall natural capital impact, highlighted the fact that Las Cruces hydroelectric project does not fall into the category of renewable energy. The project will not contribute as much as it was expected by the Mexican government to reduce their GHGs in line with the Paris agreement. In this regard, it is relevant to question the decision to complete the project, which generates an overall negative cost for Mexicans. Even the financial results indicate a net loss, which will have to be covered through subsidies from the Mexican government.

We hope that these results and the assessment framework be used by decision makers and stakeholders to support discussions around this project and other big infrastructure works. The framework used in this study provide a holistic vision of all impacts and translate them into a same metric, which allows prioritization and better decision making.

1 INTRODUCTION

1.1 Case Study Context

The construction of hydroelectric dams triggers a global debate when speaking of sustainable development and when aspects related to the real costs of construction and the distribution of the externalities generated are fully considered. Some of the socioeconomic benefits created by dams include water provision for crop irrigation, electricity generation, flood control, and water supply, and they tend to spur the expansion of social infrastructures like roads and schools. Nonetheless, negative consequences are also derived from this type of project, such as the displacement and impoverishment of communities; landscape alteration; modification of natural ecosystems (terrestrial, aquatic, coastal, and marine) and stressing of surrounding biodiversity; loss of ecosystem services (ES); construction cost overruns and significant debt; as well as the unequal distribution of externalities generated (costs and benefits). One of the most disputed issues centers on the return on investment and strongly questions if this type of infrastructure is truly the best option for investing funds and public resources (World Commission on Dams, 2000). To this day the construction of hydroelectric projects remains a controversial discussion of international reach, and Mexico is no exception.

The Las Cruces hydroelectric dam is a project proposed by the Federal Commission of Electricity (CFE) of Mexico to be constructed on the Pedro Mezquital River, located in the state of Nayarit. The San Pedro is the seventh river in the country with most water flow and the only one without any dams along the Sierra Madre Occidental mountain range. The river's coastal floodplain feeds the federal natural protected area (PA) Marismas Nacionales Biosphere Reserve (RBMN), which hosts the most extensive mangrove forest on the Mexican Pacific coast (200,000 ha). The dam's construction has aroused ample controversy from different sectors of Mexican society since its proposal in 2014, owing to the river's sacred status for the Náyeri and Waxárika indigenous communities that live in the watershed and the imminent flooding of their ceremonial sites, as well as the displacement of some members of these communities. The San Pedro River sustains the wetlands of Marismas Nacionales in the lower part of the watershed, and its flooding and sediment transport regimes are fundamental for the local economy.

The Las Cruces hydroelectric dam illustrates the complex socioeconomic and environmental dynamics associated with these types of infrastructure and development projects, which involve distinct sectors of society and levels of government with particular interests that do not necessarily overlap. Analyzing the impacts of these projects—through a thorough assessment where the costs and benefits of construction over social and natural capital are identified and evaluated for the short, mid, and long term—is fundamental to understanding the project's distribution of both positive and negative externalities among Mexican society and therefore inform decision-making. The development of similar projects has shown that the positive and/or negative impacts of hydroelectric operations in ecosystems can be significant, while it does not necessarily result in social and economic development equal to the costs incurred by society.

Valuing the impact of the Las Cruces hydroelectric project on natural and social capital provides a fresh perspective, through a high-quality assessment framework that takes into account nature-society interactions over the course of the project. Possible changes brought by the dam's construction affecting social capital (e.g. population displacement, disturbed religious sites, and employment) and natural capital (e.g. changes in carbon capture and storage, coastal erosion, and changes in water and biodiversity quality, among others), were evaluated using the latest methodologies, lending visibility to the project's potential externalities.

As of January 2017, the most recent news indicated that the project was inactive, and this past July, a judge ruled in favor of the appeal brought forth by the Náyeri and Wixárika communities against the Ministry of the Environment, and Natural Resources (SEMARNAT), the National Water Commission (CONAGUA), and the CFE. The appeals court ruled that granting permits for the construction of the Las Cruces hydroelectric dam was unlawful due to its violation of the human rights of the indigenous communities of Nayarit.

1.2 Objectives

This study aims to present quantitative and qualitative information on the cost-benefit analysis (positive and negative) of the economic, social, and environmental aspects of the Las Cruces hydroelectric project in the San Pedro Mezquital River watershed (Nayarit State). It is an objective analysis that incorporates publicly accessible information and data about this project, supporting the transparency in decision-making on the part of authorities in the three levels of government and the legislative bodies of Mexico, while also facilitating civic participation.

Specific objectives:

- Carry out an economic valuation of the possible changes in ecosystem services in the basin as a consequence of the dam's construction.
- Determine, through cost-benefit analyses, the magnitude and distribution of the costs and benefits that the project would generate among the various affected stakeholders and society as a whole.
- Develop a contextualized comparison of the Las Cruces hydroelectric project's externalities with other sources of electricity in Mexico.

1.3 Environmental and Social Impact of Dams

Throughout the world, the anthropogenic alterations of river watersheds as a result of constructing dams have reached significant proportions. There are over 45,000 dams built in 140 countries with dikes greater than 15 m in height (30,000 are located in China; World Commission on Dams, 2000), and they have the capacity to retain more than 6,500 km^3 of water

(Avakyan and Lakovleva, 1998), that is, 15% of the planet's annual river flow (Gornitz, 2000). North America and Central America possess more fluvial systems of significant size than any other continent; however, their average water supply is less than the African, Asian, and South American watersheds (Nilsson et al., 2005).

The environmental impacts of dams on aquatic and riparian ecosystems have been widely described. These affect both, the upper section of the watershed above the hydroelectric construction site, as well as the middle and lower sections. There are many levels of impacts: first-order effects include physical, chemical, and geomorphological changes that result in a physical blockage of the aquatic system, altering the natural distribution and seasonal flow of the river. Second-order effects are characterized by changes in primary biological productivity of the affected river, the adjacent ecosystems, and those systems dependent on the hydrologic dynamics of the river, like wetlands. Third-order effects alter the aquatic fauna of the river (especially fish) as a consequence of the afore-mentioned impacts: the physical blockage of the natural distribution and migratory patterns of species through the river and alterations in the abundance and availability of plankton (Humborg et al., 1997; Nilsson and Berggren, 2000; Jansson et al., 2000).

The environmental impact of dams can be observed from the beginning of construction onwards, and the impact's severity can increase with time while the hydrogeological alterations in the intervened ecosystem persist. The effects are varied, depending on the section of river that is analyzed. In the area subject to flooding by the dam, terrestrial ecosystems would be eliminated and the change in river flow, previously turbulent, would affect the lotic biota, a consequence of the decrease in dissolved oxygen levels. Additionally, the reservoirs generate greenhouse gas emissions, sedimentation, and a significant release of nutrients within the reservoir affecting water quality (Louis et al., 2000; Chang and Wen, 1998; Rosa et al., 2004).

Following the construction of a dam, ecosystems dependent on river hydrological cycles—like wetlands—are affected by the manipulation of the river, changes in its flow, and changes in flooding and sediment regimes, especially in the lower part of the watershed. These effects provoke a decrease in humidity transfer to lands adjacent to the river, which in turn results in a loss of naturally flooded lands and consequently a reduction in productivity within these ecosystems, a reduction in water quality, and changes in the fertility of the floodplain (World Commission on Dams, 2000). The dynamics of sediment deposition in deltas and beaches are also modified, in addition to the aquatic communities present in these environments (Tockner and Standford, 2002; Prowse et al., 2002; Poff et al., 1997; Lemly et al., 2000). A direct effect of dams, as already mentioned (third-order effects), is the fragmentation of the fluvial ecosystem due to dam construction; this impedes the dispersal and migration of organisms through the river, causing a population and species loss of freshwater fish (Arthington and Welcomme, 1995; Gehrke et al., 2002; Penczak and Kruk, 2000).

The social impact caused by the construction of dams refers to the direct and indirect consequences that human populations experience with the development of these infrastructure projects, in large part caused by the changes in ecosystems and ES previously provided by the river. The displacement and relocation of human settlements due to flooding is a direct impact that can cause adverse effects on people's health, as well as substantial changes in the use of the watershed land (Gillet and Tobias, 2002; Indraduby et al., 1998).

The anthropogenic pressures on dammed rivers are greater than those on unaltered rivers, as they must withstand stronger water resource exploitation for irrigation and close to 25% more economic activity per unit of water. This kind of information is highly relevant to decision-making and water resource management, especially taking into account the projected effects of climate change at the global scale and the decreasing availability and increasing demand for water (Nilsson et al., 2005).

1.4 Area of Study

1.4.1 San Pedro Mezquital River Watershed

Its hydrologic contribution, its biogeography, and its status as the last dam-free river crossing the Sierra Madre Occidental make the San Pedro Mezquital River one-of-a-kind in its class. It is the seventh river with the most flow volume in the country, making it the main source of freshwater in the south of the state of Durango and one of the principal sources of water that feed the RBMN in Nayarit's coastal floodplain. Along its 540-km length and the 2,767,406 ha that span its drainage basin, the San Pedro River connects the Chihuahuan Desert with the Gulf of California, being the only river on the North American continent to unite two biogeographic regions. The great diversity of ecosystems and species associated with the San Pedro watershed has earned it numerous measures of protection and recognition at the national and international level, both in the upper areas (Michilía Biosphere Reserve–CONANP 1979; Biodiversity Hotspot for pine/oak forests in the Sierra Madre–CI 1998; Priority Terrestrial Region Guacamayita–CONABIO 2000; Sierra de Órganos National Park–CONANP 2000), and in the lower coastal floodplain where Marismas Nacionales is located (WWF/Gonzalo Río Arronte Foundation I.A.P. Alliance). The San Pedro River flows into the coastal lagoon system of Mexcaltitlán, enriching marine-coastal productivity through the Camichín estuary and a network of natural and human-modified channels in the last three decades. The estimated, annual average of the San Pedro River's water volume is 2,734.57 hm^3, and it has an average flow of 84.06 m3/s with monthly average flows between 3 m^3/s and 303 m^3/s (MIA PH Las Cruces).

The San Pedro Mezquital River is not only vital for the natural landscapes and ecosystems that it runs through; it is also a source of livelihood for more than 800,000 residents of three states (Durango, Zacatecas, and Nayarit), 26 municipalities, and 1,766 towns. This basin is also home to four ethnic groups with approximately 34,000 people between Durango (South Tepehuanes and

Mexicaneros) and Nayarit (Coras or Náyerit and Wixákiras or Huicholes). Economic activities in the river watershed include agriculture, animal husbandry, forestry, tourism, fishing, and shrimp and oyster aquaculture in the lower part of the drainage basin. In Nayarit, the San Pedro River supplies water for irrigated and dryland farmed crops, permitting the production of beans, maize, tobacco, sorghum, rice, fruits, and vegetables, to name a few. The extraction of water from the watershed, both subterranean and superficial, is carried out mainly by the agricultural sector (60% and 58%, respectively), followed by the urban public sector (3%–27%) and aquaculture (40% of superficial water extraction); other lower-demand uses include the industrial sector (4% of subterranean water extraction) and the livestock sector (1% of subterranean extraction). Four of the six watershed aquifers located in Durango are currently in a state of overexploitation. Only the Valle del Mezquital (Durango) and the San Pedro-Tuxpan (Nayarit) aquifers persist in a state of sub-exploitation. The growing demand for water is one of the threats the San Pedro watershed faces (WWF/Gonzalo Río Arronte Foundation I.A.P. Alliance).

1.4.2 The Lower San Pedro River Watershed Wetlands: Marismas Nacionales Biosphere Reserve

Marismas Nacionales

In the lowest part of the watershed, after flowing into the coastal floodplains, the San Pedro Mezquital River empties into wetlands known as Marismas Nacionales. Their 3,103 square kilometers stretch through the states of Nayarit and Sinaloa and their eight municipalities (Escuinapa, Huajicori, Rosamorada, Rosario, San Blas, Santiago Ixcuintla, Tecuala, and Tuxpan). This coastal mangrove and lagoon system is the most extensive in all of Mexico (310,300 ha), and includes halophile communities and tropical deciduous forests associated with wetlands; its soils, rich in nutrients, are used for agriculture, livestock, and forestry. Its importance for conservation resides in its high productivity, its biodiversity, and its high level of endemism (especially for vertebrates and insects), all of which have bestowed it with numerous protection measures (Table 1). Marismas Nacionales is home to more than 460 vertebrate species, of which 51 are endemic, and 60 are currently endangered as a result of the deterioration, overexploitation, and destruction of their habitat (WWF/Gonzalo Río Arronte Foundation I.A.P. Alliance).

The Marismas Nacionales area was declared a federal Protected Area (PA) Biosphere Reserve (May 12, 2010) under the administration of the CONANP, and it encompasses 133,854 ha in the state of Nayarit including the municipalities of Acaponeta, Rosamorada, Santiago Ixcuintla, Tecuala, and Tuxpan. Its surface area hosts 20% of the mangrove forests of the country, and the island of Mexcaltitán, an iconic site of Aztec culture, is located in its lagoons (SEMARNAT, 2013).

Table 1. Instruments of recognition and protection for Marismas Nacionales (source: WWF/Gonzalo Río Arronte Foundation I.A.P. Alliance).

1992	Western Hemisphere Shorebird Reserve Network
1995	Wetland of International Importance - RAMSAR
1998	Marine Priority Region - CONABIO
1998	Important Bird Area - BirdLife International
1998	Endemic Bird Area - BirdLife International
2000	Terrestrial Priority Region - CONABIO
2002	Priority Hydrologic Region - CONABIO
2010	Biosphere Reserve - CONANP
2011	Water Reserve - CONAGUA

The environmental problems that Marismas Nacionales faces do not only consist of the loss of its primary habitat—they also threaten the broad array of ES that these mangroves and coastal lagoons provide for Mexican society. The complex social, economic, and governance conflicts of the area are brought to light by numerous threats, including degradation in the quality and function of the ecosystem; draining of wetlands as a result of land use change for pasture expansion and both dryland and irrigated agriculture; fragmentation from infrastructure construction (canals and highways); habitat destruction for shrimp farms; increased water demand for agricultural use; the deterioration in water quality throughout the river watershed; and the salinization of wetlands and adjoining lands (WWF/Gonzalo Río Arronte Foundation I.A.P. Alliance; SEMARNAT, 2013; CONANP, 2014). Moreover, the effects of climate change and the construction of hydroelectric dams on rivers feeding the area are now considered threats to this PA as well.

Wetland Ecosystem Services

Wetlands provide numerous ecosystem services with many benefits of high value both for people and the economy. For the most part, they have to do with water services (e.g. water provision, regulation, and purification, as well as aquifer recharge); however, they also include functions related to nutrient recycling, climate change mitigation and adaptation, employment security and community sustenance, recreation, tourism, scientific and traditional knowledge, and cultural values of identity and spirituality (Table 2). Additionally, wetlands are critical ecosystems for strategic planning for issues in water and food security (CDB, 2015). Given that a large variety of the social and economic activities in the world depend on the availability of water and the ES that wetlands provide for society, it is no surprise that the *Millennium Ecosystem Assessment* (MEA, 2017) estimated that they deliver a total value of 15 trillion USD per year. As a reference and point of comparison, Table 3 contains a summary of the total economic value of selected biomes (De Groot et al., 2012).

Table 2.Classification of wetland functions (source: Schuyt and Brander, 2004).

Wetland Functions	
Regulation function: regulation of ecological processes	Nutrient retention and recycling
	Human waste retention and recycling
	Organic waste retention and recycling
	Aquifer recharge
	Aquifer discharge
	Natural control of flooding and flow regulation
	Erosion control
	Salinity control
	Water filtration
	Climate stabilization
	Carbon capture
	Sustained breeding habitats
	Sustained ecosystem stability
	Sustained integrity of other ecosystems
	Sustained biological and genetic diversity
Transport function: providing space for activities	Agriculture, irrigation
	Livestock
	Harvest of wild products/resources
	Transport
	Energy production
	Tourism and recreation
	Human dwellings and settlements
	Breeding areas and habitats for plants and animals
Production function: providing resources	Water
	Food
	Wood for fuel
	Medicinal resources
	Genetic resources
	Primary materials for construction and industrial use
Social value function: contributing to mental wellbeing by providing scientific, aesthetic, and spiritual value	Research, education, and monitoring activities
	Cultural uniqueness, rarity, and heritage
	Scenic beauty

Table 3. Total Value of Ecosystem Services (source: De Groot et al., 2012).

Ecosystem Services	Marine Ecosystems	Coral Reefs	Coastal Systems*	Continental Wetlands	Freshwater (rivers/lakes)	Tropical Forests	Temperate Forests	Forests	Grasslands
Total Economic Value (USD/ha/year)	352,249	28,917	193,845	25,682	4,267	5,264	3,013	1,588	2,871

*Coastal systems include estuaries, continental shelves, and seagrass; they exclude mangroves, swamps, and salt marshes.

The economic value of the benefits provided by wetlands has been systematically higher per unit area than other ecosystems—by at least one order of magnitude—and the majority of this value is derived specifically from wetlands' function in water regulation (e.g. risk reduction from water-related natural disasters). The ES provided by wetlands as buffer zones for flood control reach 464 USD/ha/year (Schuyt and Brander, 2004). Regarding their ability to sequester and store carbon, wetlands play a strategic role, surpassing the majority of other ecosystems. In terms of biodiversity, wetlands are highly biodiverse habitats with high numbers of ecologically and economically important species living within these ecosystems or depending on them at some point in their lifecycle. Wetlands are of particular importance to migratory bird species, because they provide nesting, breeding, feeding, and resting grounds. For urban and rural communities that live close to or within these ecosystems, wetlands are a direct source of work and sustenance, providing breeding and husbandry grounds for economically valuable species (e.g. fisheries), sources of water for agriculture, sources of primary materials (timber), and flood control, among others (CDB, 2015). Figure 1 illustrates wetlands' ecosystem services and their values provided. The number of observations used in the analysis of each ES is included in parenthesis.

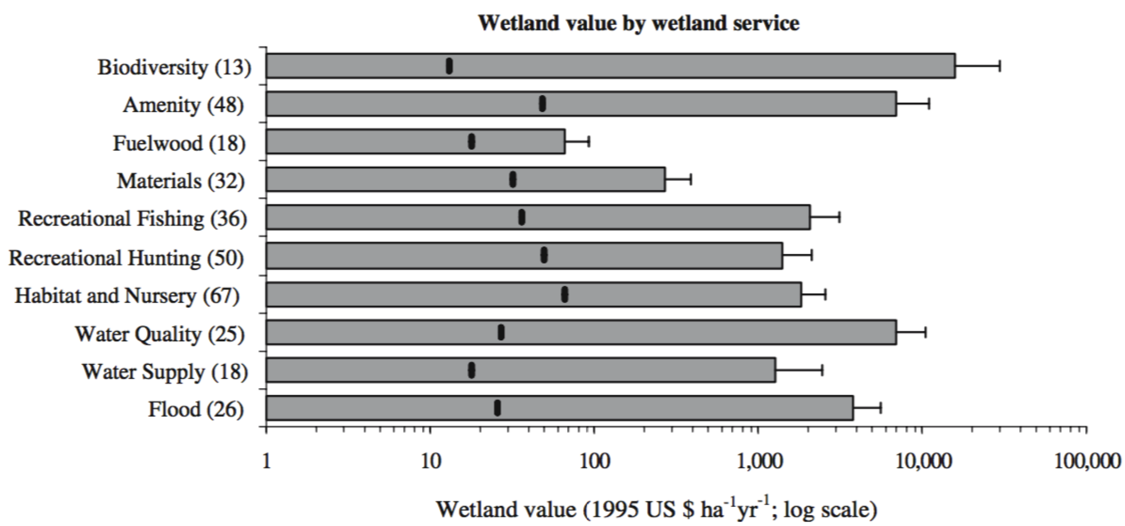


Figure 1. The value of wetlands on the basis of their Ecosystem Services (source: Brander et al., 2006).

Some of these services will be explored in more detail along with the economic value generated for society and local economies throughout this study.

1.4.3 The Las Cruces Hydroelectric Project

The Las Cruces hydroelectric dam is an infrastructure project proposed by the CFE of Mexico and backed by the government of the state of Nayarit. It seeks to contribute to meeting the predicted demand of electricity for the western region of the country, according to growth estimates for demand (an average of 3.7% in annual growth between 2012 and 2016; SENER, 2012) and to the capacity requirements that the Electric Sector Program for Construction and Investment 2012–2016 (POISE) is based. The additional 240 MW of capacity that the Las Cruces hydroelectric project would be generating (project net capacity) would satisfy the system's demands (in peak hours) at a lower total cost in the long term (lower operation costs of the electric system thereby avoiding the use of fossil fuels), and with a high potential for energy accumulators (reservoirs), allowing for its operation based on demand necessities (MIA PH Las Cruces).

The dam requires 5,349.80 ha in the central part of the state of Nayarit, over the course of the San Pedro Mezquital River, 250 m upstream of its confluence with the El Naranjo River (22˚ 05' 19" N and 104˚ 57' 03" W) (Figure 2). Of its total extension, 4,506.20 ha would be flooded to form the Las Cruces reservoir and 276.61 ha for the dam and additional infrastructure. The project construction would occupy 228.57 ha, and the marginal paths on both sides would require 338.42 ha; the concrete wall would measure 188 m in height. The project is expected to generate 751 GWh/year by a capacity factor of 0.36 (an average of 8.64 h/day/year). An investment of 7,995 million pesos (MDP) (639.6 million USD) would be required over four years (49 months) according to the CFE, which represents approximately 5,000 jobs in the peak phase of construction (second and third year) and another 5,000 indirect jobs (MIA PH Las Cruces). More detailed information about these jobs, their fulltime equivalent, and wages is lacking.

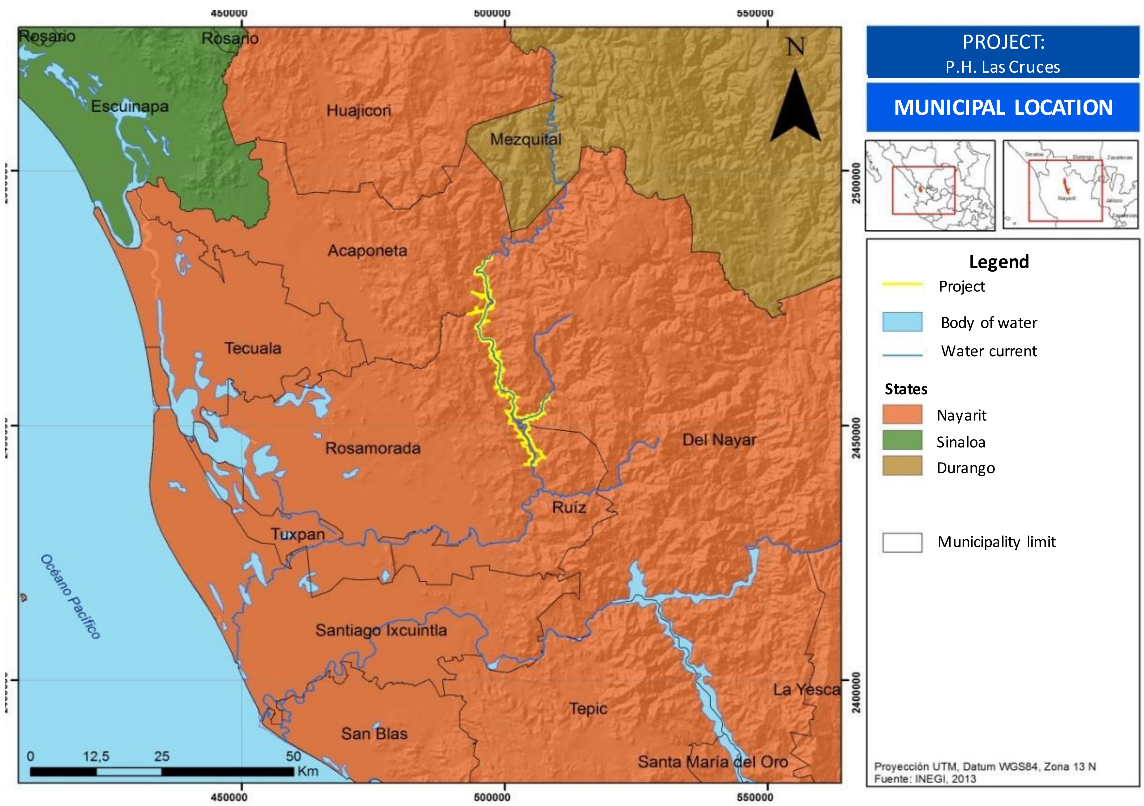


Figure 2. Location of the Las Cruces Hydroelectric Project, Nayarit State (source: MIH PH Las Cruces; translation done by authors).

The Environmental Impact Statement (EIS) of the Las Cruces hydroelectric project indicates that the project is in line with the objectives and strategies of the current federal planning instruments (2013–2018), including the National Development Plan, the Sectoral Energy Program, and POIS 2012–2026, contributing to the diversification of energy sources and a reduction in greenhouse gas (GHG) emissions. Regarding the conservation programs mentioned in the EIS that apply to the region and regulate land use (General Ecological Zoning Program; Ecological Zoning Program of the State of Durango; Marine Ecological Zoning Program of the Gulf of California; Ecological Zoning Plan of the Coastal Zone of El Rosario Municipality, Sinaloa; Regional Management Plan for Conservation, Management, and Sustainable Use of the Marismas Nacionales Mangroves, Nayarit), the Las Cruces hydroelectric project is described as not violating the decrees of said programs, and it is mentioned that the actions and measures in mitigation, control, prevention, restoration, and compensation of environmental damages and impacts are in accordance with the strategies and actions of the environmental policy instruments of Mexico (MIH PH Las Cruces).

Observing the identification, description, and evaluation of environmental impacts tied to the project that the CFE mentions in the EIS, it should be noted that several of these do not indicate mitigation and/or compensation measures, even when the certainty of the magnitude of impact is high. In other cases, the magnitude of impact is described as medium or low; however, the results presented in this study indicate the opposite (e.g. substitution of aquatic ecosystems without specifically mentioning wetlands, modification of sediment and nutrient transport in the river and lagoon system, and modification of morphogenetic processes in the floodplains and wetlands), and therefore a revision of the environmental impact mitigation and compensation plan identified by the CFE is recommended, as well as a revision of their general evaluation. TablTable 4 lists the environmental impacts considered in this study and for which the CFE did not indicate a measure of mitigation and/or compensation; the complete list of environmental impacts published in the EIS is presented in Annex 6.1.

Table 4. Environmental impacts (included in this study) of the construction and operation of the Las Cruces Hydroelectric Project without mitigation and compensation measures (source: MIA PH Las Cruces).

Impacts	Impact Category	Mitigation	Compensation	Link to Preexisting Driver	Geographic Reach (UAR)	Certainty of Impact Magnitude
Impacts from construction of the reservoir						
Substitution of aquatic ecosystems	2		C		1	Medium
Generation of GHG from anaerobic decomposition	1				1	High
Changes in geomorphological processes downstream of wall	1			Yes	3–4	Low
Impacts from operation of the hydroelectric generation system						
Changes in land use of floodplains	2			Yes	3–4	High
Modification of productive activities in coastal floodplains	2				3–4	High
Modification of nutrient and sediment transport in the San Pedro River	1		C		2–4	Low
Modification of morphogenetic processes in floodplains and wetlands	1			Yes	3–4	Low
Modification of nutrient and sediment transport in lagoon system	2		C	Yes	2–4	Low

The critical issue is water management of the San Pedro River for generating energy—it connects the hydroelectric project with the four PAs present in the zone, particularly Marismas Nacionales, and the question remains of how the dam's construction will affect the ecosystems tied to the river's hydrology. The CFE proposes mitigation measures (e.g., a regime-change dam–PCR) that reach minimum and maximum flow rates and can simulate and stabilize daily flow and the river's natural flow regime, therefore avoiding significant repercussions on the Marismas Nacionales ecosystem. Details of these environmental impacts and the mitigation and compensation measures identified, described, and evaluated by the CFE can be consulted in the project's EIS, where they divide direct impacts caused by the construction and creation of the reservoir from impacts of the operation of the hydroelectric system.

2 Methodology and Data Sources

2.1 General Introduction to Impact Valuation

Impact valuation attempts to capture society-nature-economy interactions through an innovative approach on what is considered to be of value. The concept of impact valuation goes beyond monetization and refers to the process of estimating the relative importance, the value, and the utility of natural capital for society. This is why valuations can be qualitative, quantitative, or monetary or even a combination of all three (Natural Capital Protocol, 2017).

Figure 3 illustrates how economic activities have direct impacts on social capital (1a) and natural capital (1b). In this cycle, we as a society depend on a functioning economy to maintain our wellbeing, and at the same time, our economies depend on the existence of social capital in order to operate (2), creating numerous impact pathways (3) (e.g., work conditions, industrial security, occupational health, and salaries, among others).

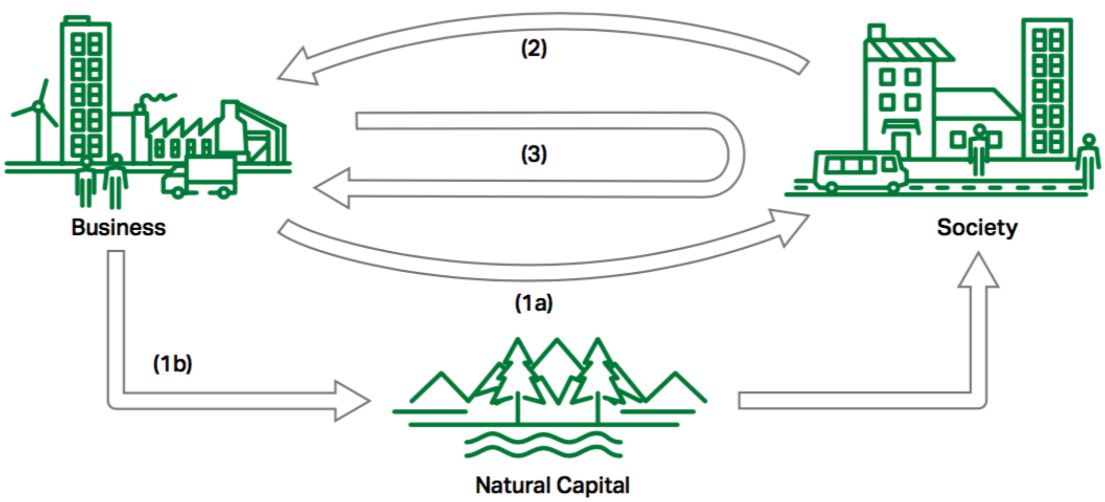


Figure 3. Connections between the economy (businesses) and social and environmental capital (WBCSD, 2017).

More details about the methodology of impact valuation can be consulted in the most recent protocols used by the private sector, including the Natural Capital Protocol (Natural Capital Coalition, 2016) and the Social Capital Protocol (World Business Council for Sustainable Development - WBCSD, 2017) (Figure 4). Both documents form the methodological basis for the study in this report. The conceptual essence of impact valuation is based on the definition of “impact pathways”, which facilitate the comprehension of changes incurred, from input and activities to the output, outcome, and impacts.

Figure 4. The most recent Protocols on Natural and Social Capital (NCP, 2016; SCP, 2017).

Impact maps are build based on the identification of the different impact pathways that together comprise the conceptual framework of the project being analyzed. An illustrative example of social capital impact map is shown in Figure 5.

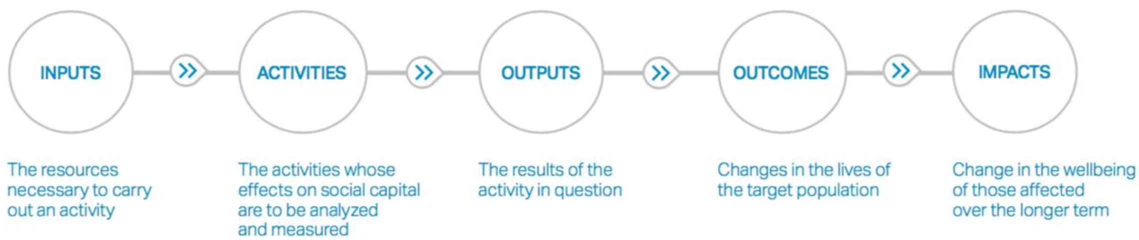


Figure 5. Illustration of an impact pathway (WBCSD, 2017).

The last step in the impact valuation approach focuses on economically valuing the impacts analyzed in the process. There are different techniques for developing economic valuations; some of the more commonly employed can be seen in Figure 6.

Classes

Types

Figure 6. Valuation techniques (source: Dupras and Reveret, 2015).

In the present study, the output analyzed were defined as the direct consequences of the changes caused by the construction of the Las Cruces hydroelectric project:

1. Social change
2. Direct impact on the site of project construction
3. Changes in the flooding regime
4. Changes in the sediment regime

Each one of these impact pathways and their results are described in the various sections of this report, analyzing the potential changes between the situation prior to and following the construction of the reservoir during a period of 25 years, starting with the first year of the dam's construction (Figure 7).

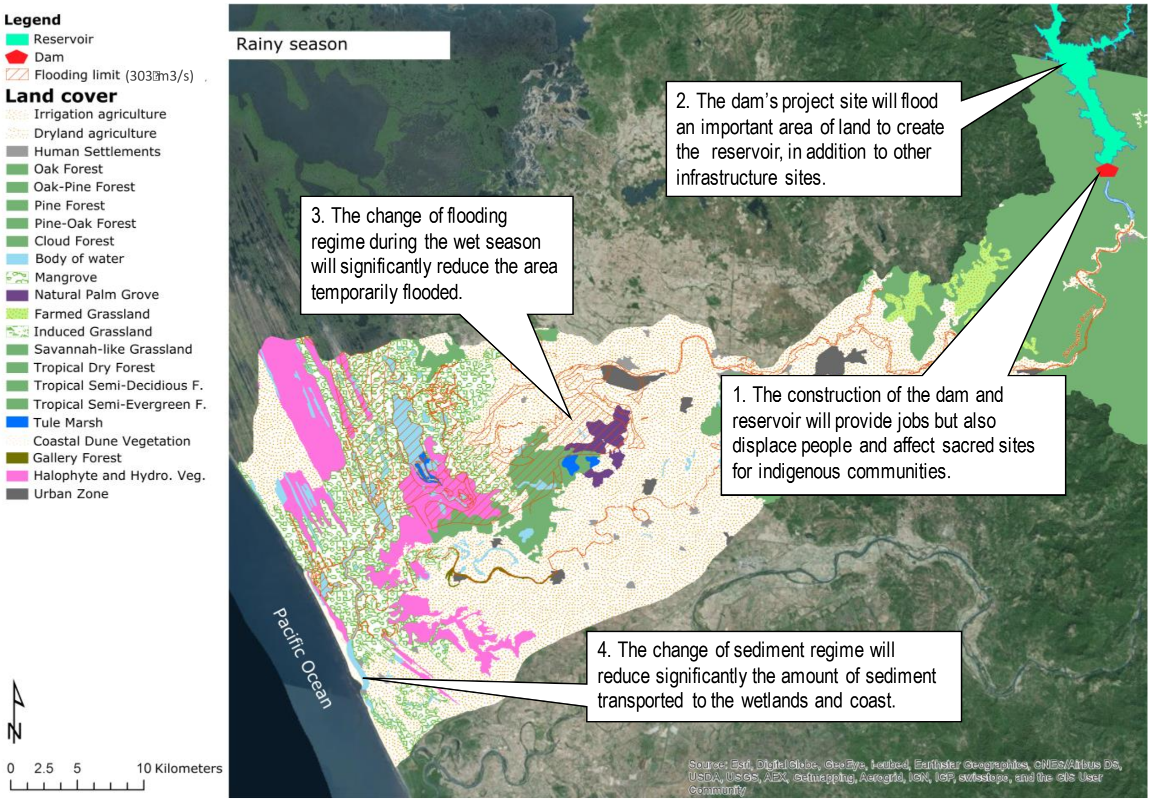


Figure 7. Principal impacts of the construction of the Las Cruces hydroelectric project (source: created by authors).

Characterizing the impact pathways that the construction of the Las Cruces hydroelectric project would generate permitted the identification of potential results that were evaluated using different valuation techniques. These are presented in Figure 8 and are described in detail in the following sections of this report. These are not the only impacts (positive and negative) tied to the project; there are others whose identification was not possible, or there is no published data permitting their analysis.

Output	**Social changes**	**Project's impact**	**Flooding regime**	**Sediment regime**
Outcomes	Displaced population Sacred sites Jobs *Tourism activity*	Land covered by reservoir Reservoir GHGs emissions Construction GHGs emissions	Carbon Fisheries Biodiversity/habitat Water quality Agriculture	Water quality Carbon Fisheries Biodiversity/habitat Extreme events Agriculture losses

Figure 8. Frame of reference for attained results (source: created by authors).

The following illustration contains a graphic representation of the potential results that the construction of the Las Cruces hydroelectric project could generate (Figure 9) in chronological order and according to the period considered for the analysis of this study (25 years). The dotted lines (vertical) indicate the three main phases of the project through which their impacts were evaluated, starting with the dam construction phase (5 years), on toward the period of reservoir filling (3.4 years), finishing with the operational phase when the project would be generating energy (16.6 years). Clearly, the type and value of positive (in green) and negative (in yellow) externalities created by the project vary in each of these phases.

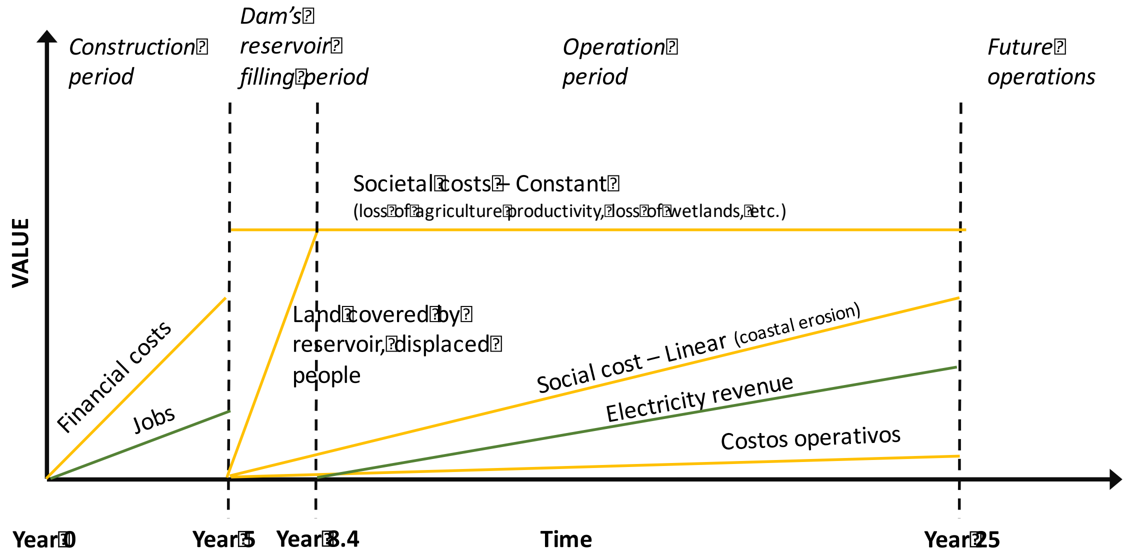


Figure 9. Project timeline and distribution of social and financial values (source: created by authors).

2.2 Discount Rate

A discount rate is a financial factor commonly used to reflect monetary value in time, and it is employed as a tool for evaluating long term costs and benefits. As a consequence, the value of money is lower in the future than in the present. The basic discount rate applied in financial analysis would consider a value close to the depreciation value or to interest rates. For projects analyzed based on impacts on social and natural capital, the discount rate value varies depending on the valuation technique used, whether the economic valuation is based on costs or market values, or even the willingness to pay (WTP) or willingness to accept (WTA). In general, the discount rates applied to social impact valuation are greater than those used in financial analysis.

In the Excel model designed for this study, a dynamic parameter was integrated that allows for easy adjustment of the discount rate value. Depending on the audience, different discount rates can be used. The private sector, for example, tends to consider higher discount rates for environmental and social values; whereas the rates used by non-governmental organizations (NGOs) and governments for the same criteria tend to be lower.

For the purposes of this study and to maintain consistency with the concept of sustainability, a discount rate was not used to present results, assuming that the future value is equally as valuable as the present value. This decision reflects the opinion of the authors, which may not be shared by other stakeholders. In Annex 6.2, the study results are presented using a discount rate of 3.9% (the average inflation rate for Mexico over the past six years was used as a reference for defining the discount rate).

2.3 Value Transfer, Inflation, and Purchasing Power Parity

Some of the following valuations are based on the results obtained by studies developed in a context and geography different from that of this project. The values that are transferred from one study to the next need to be adjusted in order to incorporate factors inherent to the context that could internally and/or externally affect the values to be used (e.g., inflation and purchasing power parity, or PPP), as well as to incorporate the value change in time. The use of value transfers is indicated in the methodology description further below; however, no inflation or PPP adjustments were made, given that the value transfers were taken from meta-analysis studies, covering a great number of publications with different dates and geographies. Additionally, the different valuation methods used in each of the studies included in the meta-analysis were often not included, thus limiting the possibility of adjusting the transfer values. These were considered to be unnecessary and not significantly contributing to the results, as the variability derived from internal factors was much greater than from those external factors.

2.4 Sensitivity Analysis

The study's sensitivity analysis was developed with the aim of understanding how results change based on the variability of different key parameters. Both low and high values were used for most of the parameters integrated in the model built. These values (low and high) represent the optimal or least suitable conditions for executing the project. The low estimates were used to illustrate the most favorable conditions in which the project could be developed, reducing costs and maximizing revenue, while the maximum values or high estimates illustrate the opposite scenario, which is to say higher costs and lower revenue. The low and high values used for each analyzed variable are shown in Table 5 and Table 6; the average values are considered to be the most reliable for analyzing the feasibility of the project, and they are presented in the results section of this report as the main result from the model generated. In the Excel model, it is possible to modify the value (minimum, maximum, average) of each variable to more easily observe the variability of each factor and its related result.

Table 5. Summary of values used in sensitivity analysis (source: created by authors).

		Average values estimates / without discount rate	Minimum values estimates / without discount	Maximum values estimates / without discount
Social Impacts	**Jobs**	Monthly salary of 3,918 MXN	Monthly salary of 4,955 MXN, assuming a living salary in Mexico (2017 data)	Monthly salary of 1,680 MXN, assuming a minimum wage salary in Mexico (2017 data)
	Sacred Sites	Cost value of receiving psychological support, per consult per person: 800 MXN	Cost value of receiving psychological support, per consult per person: 500 MXN	Cost value of receiving psychological support, per consult per person: 2,500 MXN
	Displaced Population	Cost value of receiving psychological support, per consult per person: 800 MXN	Cost value of receiving psychological support, per consult per person: 500 MXN	Cost value of receiving psychological support, per consult per person: 2,500 MXN
Project Impacts	**Land Covered by Reservoir**	Sum of ecosystem services (ES) per hectare provided by area subject to flooding from dam: 26,059 MXN/ha/year	Sum of ES per hectare provided by area subject to flooding from dam: 13,128 MXN/ha/year	Sum of ES per hectare provided by area subject to flooding from dam: 232,820 MXN/ha/year
	GHG Emissions from Reservoir	Social cost of carbon: 1,280 MXN/tCO2e. Also, GHG emissions produced by the reservoir are estimated at: 523 mgC/m2/day for CO2 and 68 mgC/m2/day CH4	Social cost of carbon: 640 MXN/tCO2e. Also, GHG emissions produced by the reservoir are estimated at: 386 mgC/m2/day for CO2 and 24 mgC/m2/day CH4	Social cost of carbon: 3,282 MXN/tCO2e. Also, GHG emissions produced by the reservoir are estimated at: 660 mgC/m2/day for CO2 and 112 mgC/m2/day CH4
	GHG Emissions from Project Construction	Social cost of carbon: 1,280 MXN/tCO2e	Social cost of carbon: 640 MXN/tCO2e	Social cost of carbon: 3,282 MXN/tCO2e
Flooding Regime	**Water Quality**	Value of ES of water filtration per hectare: 558 MXN/ha/year	Value of ES of water filtration per hectare: 443 MXN/ha/year	Value of ES of water filtration per hectare: 673 MXN/ha/year
	Biodiversity / Habitat	Value of ES of biodiversity/habitat per hectare: 558 MXN/ha/year	Value of ES of biodiversity/habitat per hectare: 246 MXN/ha/year	Value of ES of biodiversity/habitat per hectare: 853 MXN/ha/year
	Carbon Capture and Storage	Social cost of carbon: 1,280 MXN/tCO2e	Social cost of carbon: 640 MXN/tCO2e	Social cost of carbon: 3,282 MXN/tCO2e
	Fisheries	Value of ES of fisheries per hectare: 886 MXN/ha/year	Value of ES of fisheries per hectare: 0 MXN/ha/year, assuming the loss of breeding areas won't affect fishing resources	Value of ES of fisheries per hectare: 615,375 MXN/ha/year, assuming that the loss of breeding areas is critical for maintaining fisheries
	Agriculture	30% losses in yield from reduction in transport and deposition of sediments linked to changes in flood regime caused by project	10% losses in yield from reduction in transport and deposition of sediments linked to changes in flood regime caused by project	50% losses in yield from reduction in transport and deposition of sediments linked to changes in flood regime caused by project

Table 6. Continuation of summary of values used in sensitivity analysis (source: created by authors).

		Average values estimates / without discount rate	Minimum values estimates / without discount	Maximum values estimates / without discount
Sediment Regime	Water Quality	Value of ES of water filtration per hectare: 558 MXN/ha/year	Value of ES of water filtration per hectare: 443 MXN/ha/year	Value of ES of water filtration per hectare: 673 MXN/ha/year
	Biodiversity / Habitat	Value of ES of biodiversity/habitat per hectare: 558 MXN/ha/year	Value of ES of biodiversity/habitat per hectare: 246 MXN/ha/year	Value of ES of biodiversity/habitat per hectare: 853 MXN/ha/year
	Carbon Capture and Storage	Social cost of carbon: 1,280 MXN/tCO2e	Social cost of carbon: 640 MXN/tCO2e	Social cost of carbon: 3,282 MXN/tCO2e
	Fisheries	Value of ES of fisheries per hectare: 886 MXN/ha/year	Value of ES of fisheries per hectare: 0 MXN/ha/year, assuming the loss of breeding areas won't affect fishing resources	Value of ES of fisheries per hectare: 615,375 MXN/ha/year, assuming that the loss of breeding areas is grave for maintaining fisheries
	Agriculture	–	–	–
	Protection Against Extreme Climate Events	–	–	–
Financial Analysis	Net Results	Construction costs: 10.49 BDP. Revenue was calculated based on the following price for electricity: 542 MXN/MWh	Construction costs: 10.49 BDP. Revenue was calculated based on the following price for electricity: 935 MXN/MWh	Construction costs: 17.8 BDP. Revenue was calculated based on the following price for electricity: 542 MXN/MWh

2.5 Price of Carbon

For carbon valuation, the average value is based on the results from the meta-analysis published by Price Waterhouse and Cooper (PwC, 2015), where an extensive review of the literature on this topic is presented, indicating a median price of 78 USD/ton/CO_2-eq. The minimum and maximum values used for the sensitivity analysis were 30 USD/ton/CO_2-eq (Nordhaus, 2016; EPA, 2017) and 200 USD/ton/CO_2-eq (Moore and Diaz, 2015). The three values mentioned are based on the social cost of carbon (SC-CO_2), which are an economic measure (in USD) of the long-term damage caused by a ton of CO_2 emissions in a given year (e.g., changes in net agricultural production, human health, property damage from increased risk of flooding, changes in cost of energy system, among others) (EPA, 2017).

2.6 Delimitation of Study Area for Valuation Analysis

The delimitation of the geographic area of study subject to valuation analysis was done according to the zones vulnerable to direct and indirect impacts of the hydroelectric project; in this case, two zones were considered of interest for analysis: the project construction area including flooding areas, and the lower part of the watershed.

The direct impacts of project construction include permanent habitat modification, which is to say a change in its topography, land cover, and type of ecosystem. This would occur in an area destined for project construction, be it from flooding or removal of existing vegetation. The zones subject to direct impacts of construction make up a total of 5,493.26 ha, and include areas destined for project access points (455.66 ha), flooding areas (4,588 ha), and project work areas (449.56 ha).

The indirect effects of dam construction are a consequence of changes in hydrologic dynamics of the river in the middle and lower parts of the watershed below the dam, given that flow regulation and sediment retention are two major observed consequences of this type of infrastructure project. The lower section of the San Pedro River watershed was included in this study as a zone of interest, in which it is expected that the dam will create changes in ecosystems (e.g., coastal wetlands, lagoon systems, and beaches) and ES (e.g., fisheries, nutrient and sediment input) on which the local economy depends by virtue of the river.

The delimitation of the area of interest was carried out taking into account information on a) the hydrographic watersheds present in the region (watersheds of Acaponeta, San Pedro, Santiago, and El Palillo rivers), b) their zoning by function, and c) the active area of the river (Cotler, et al., 2007). In this case, the San Pedro River hydrographic watershed was determined according to the delimitation of watersheds by INEGI-INE-CONAGUA used by the CFE and the IES (Figure 10).

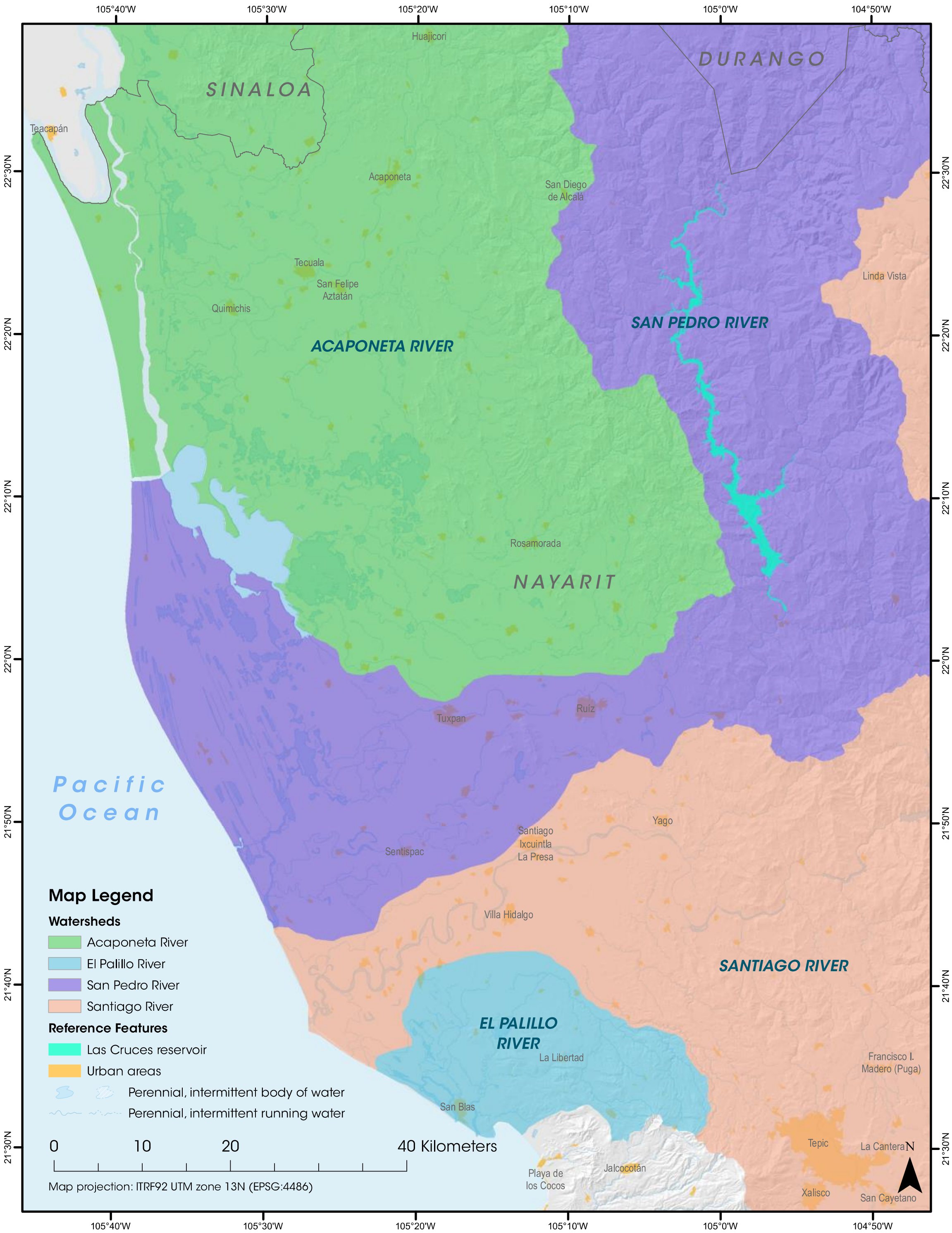


Figure 10. Hydrographic watersheds present in the general area of study (created by authors using source: Cotler H., Garrido A., Mondragón R., Díaz A. 2007. Delimitación de cuencas hidrográficas de México, a escala 1:250'000. *México: INEGI-INE-CONAGUA).*

Functional zoning of the watershed only included their lower part, i.e. the ordinary and extraordinary flooding of plains, the river terraces and ordinary and extraordinary flooding of riverbeds, and alluvial fans. This area is characterized by meandering systems and lagoons with a minimum or null slope, minimum energy, and with clear deposition processes (Garrido et al., 2009) (Figure 11).

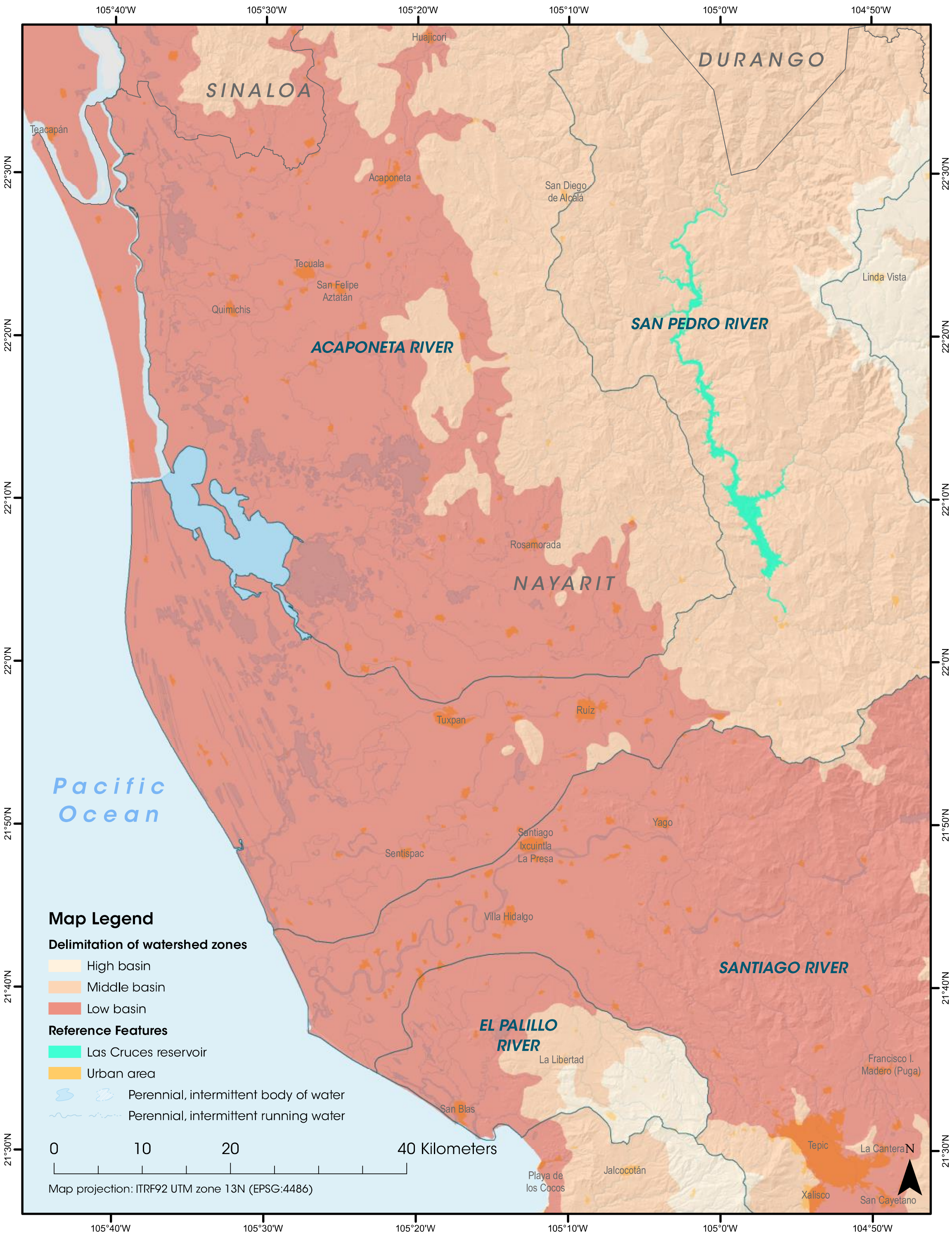


Figure 11. Functional zoning of watershed in area of study (source: Garrido, et al., 2009. Zonas funcionales de las cuencas hidrográficas de México, escala 1:250,000. México: INE, SEMARNAT).

The active area of the San Pedro River is diffused in its lower section (Marismas Nacionales alluvial plain) in terms of its water contribution (surface and subterranean), due to the confluence of other rivers and to the complex network of natural and artificial channels that run in the plain. To define the active area of the river, the Active River Area (ARA) model was used, developed by The Nature Conservancy (TNC) (Figure 12). Delimiting the study area permitted the generation of and access to processed data (geographic, environmental, economic, and social) of the region, an important input for the valuation model (Figure 13).

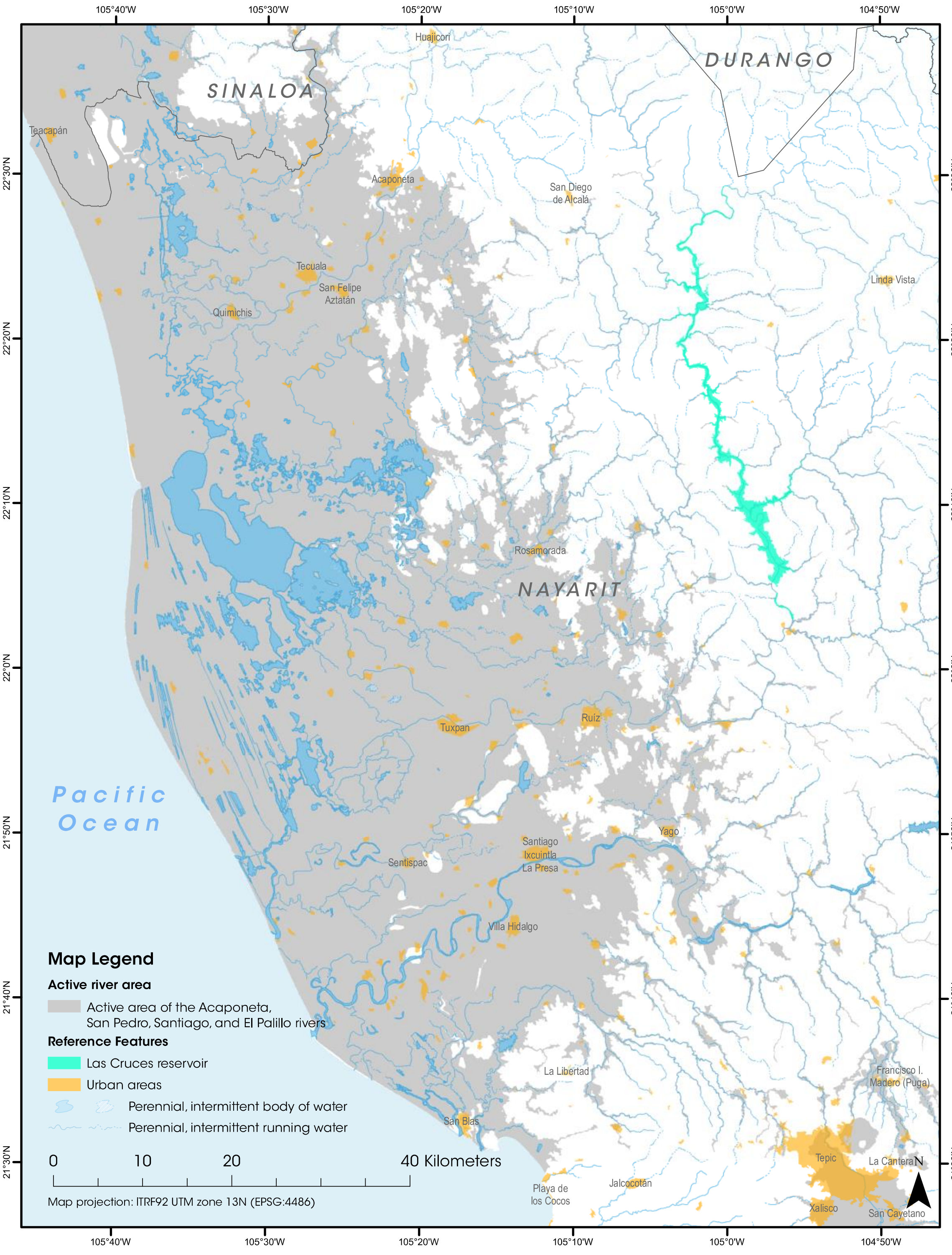


Figure 12. Active area of the Acaponeta, San Pedro, Santiago, and El Palillo rivers (source: created by authors based on Barnett and Analie, 2011. Active River Area (ARA) Three-Stream Class (3SC) Toolbox Documentation. United States of America: The Nature Conservancy).

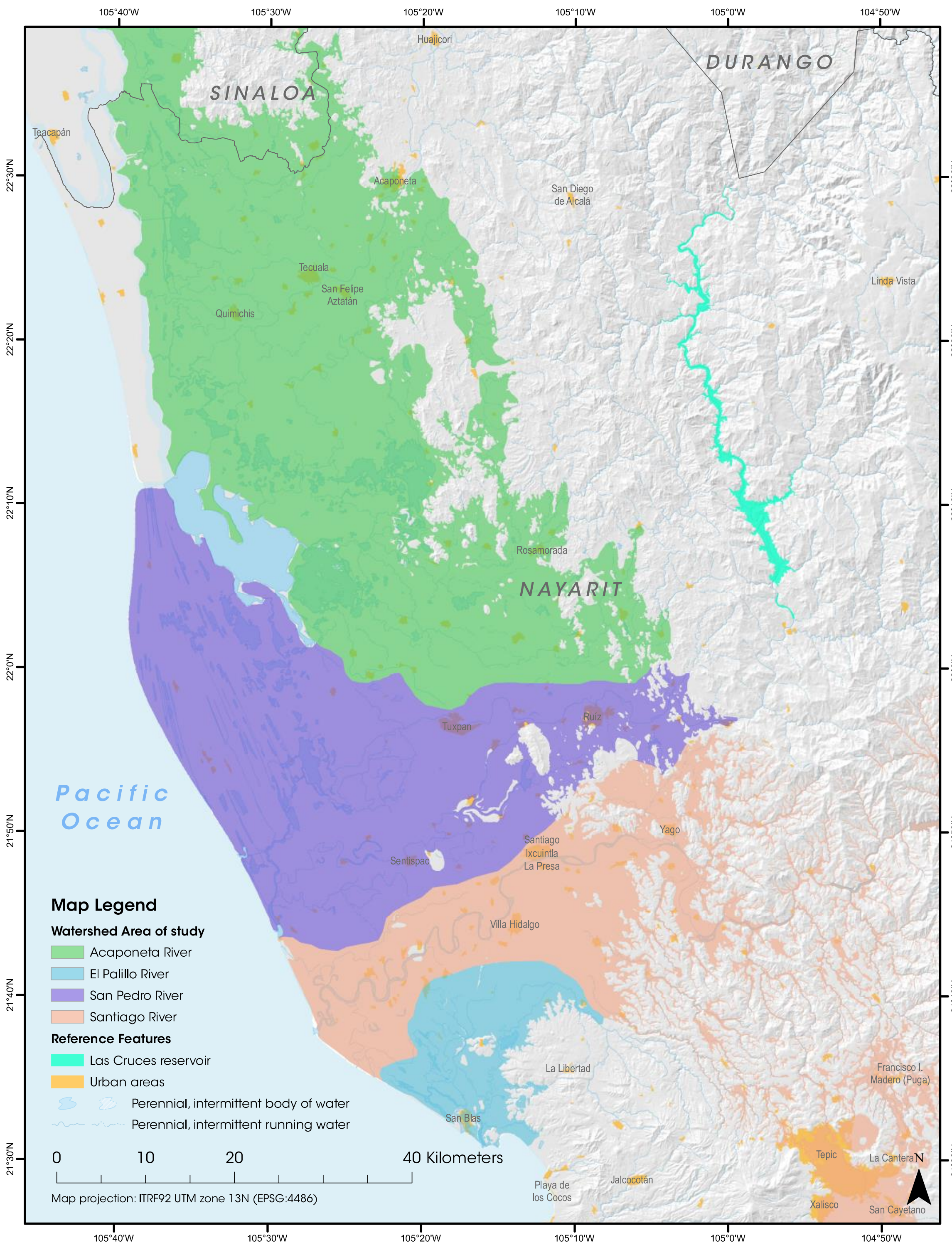


Figure 13. Area of study with delimitation of watersheds according to maps provided by INEGI-INE-CONAGUA (source: created by authors).

2.7 Literature Review and Data Collection

The results of this study are the outcome of a broad literature review of the study area, the Las Cruces hydroelectric project, and issues of particular interest associated with the valuation and cost-benefit analysis of the project; all of the sources consulted are open access. The main objective was to implement innovative methodologies in analyzing available data, thereby generating new and relevant information with an economic perspective about the social and environmental impacts that the project could cause locally and nationally. In addition, telephone interviews were conducted with some of the key stakeholders in the area with the goal of increasing knowledge of the study area, the project's context and the reactions within the territory, and specific issues related to valuation where not enough information was found or verification was required. There are technical limitations regarding the available or non-existent information on the area of study and the watershed of the San Pedro River, which restricts the accuracy of results or the tools (modeling software) that can be used for analysis.

2.8 Social Changes

2.8.1 Jobs

Although the CFE estimated four years for the project's construction (MIA PH Las Cruces), five years were used as an estimate of the real time required for building the dam (accounting for possible delays), during which 5,000 jobs would be directly created. The distribution of these jobs would not be constant during the construction phase, since during the first and fifth year, only 15% of these would be available and the job maximum (5,000) would become available during the second and third year, while in the fourth year 2,500 jobs are expected to be kept (SuMar). The majority of these jobs require low-qualification personnel (construction workers) and low wages, a fact that does not ensure that this job creation will necessarily be a positive contribution to society. To summarize, the construction of the Las Cruces hydroelectric project will create 2,800 full-time jobs (full-time equivalent - FTE) per year for the five years that it will take to build the dam or, in other words, 14,000 FTE jobs during a span of five years.

Of the 5,000 jobs required during peak construction years (years 2 and 3), SuMar estimated that 1,500 would be occupied by workers from other states with lower minimum wages that those of Nayarit (the daily wage of a person on the coastal plain is between 130 MXN and 150 MXN per day; SuMar, personal communication, July 2017), meaning that approximately 30% will not be jobs created for the local population, meaning workers will migrate from other states to the project area.

Apart from direct jobs, the CFE also calculated the creation of 5,000 other indirect jobs related to services needed for construction; however, the conjectures and calculations for reaching these 5,000 jobs are not clear. For this reason, these estimates are not included in the baseline scenario (average values) and are solely utilized in the sensitivity analysis.

The analysis used for calculating the social benefit of the project with regard to job creation varies depending on the reference used as the minimum wage that workers would be receiving. For 2017, the federal monthly minimum wage is 1,680 MXN (80 MXN/day; SEGOB, 2017[1]); this amount was applied as the minimum value generated by jobs in the scenarios analyzed. The average monthly value was taken from the standard reference for a construction worker, which exceeds 3,918 MXN/month (World Salaries Mexico, 2005[2]) and the maximum value that the project's jobs could generate was taken from an estimate of the individual living wage (minimum wage necessary for a worker to supply all of his/her basic needs) for Mexico, which is 4,955 MXN/month[3].

The social benefit of the project was calculated as the total economic value of jobs created during the five years of dam construction (Table 7). For the calculations, 14,000 FTE jobs were taken into account, since the distribution of available jobs is not 5,000 over the established period, but instead varies: 15% of this number in the first and fifth year, 100% in the second and third year, and 50% during the fourth year. The model did not include jobs for operation, which is considered negligible. The average total economic value generated by the jobs for five years is 658 MDP, with low ranges of 282 MDP and high ranges of 1.5 billion pesos (BDP). The local estimate is lower since only 70% of jobs are estimated to be occupied by local workers. In more favorable conditions (low values), 5,000 additional jobs were included as the indirect jobs mentioned previously.

The total economic values presented in the analysis should be seen as gross positive values, to which social aspects should be incorporated that are fundamental to estimating their real contribution to Mexican society. The results do not include the temporary nature of the majority of these jobs, nor do they consider job necessities for the region in the long term. Additionally, and depending on conditions (e.g., compensation for injury or accidents) and the work environment (industrial security in a high-risk setting), the jobs created by the project could cause a negative value for society if security and health are not addressed in the conditions offered to workers, and if the paid wages do not provide the minimum amount necessary for fulfilling the basic needs of the people. In this sense, the problems surrounding the subject of living wages trigger a relevant discussion, when possibly the majority of low-qualification workers do not receive the income level used in calculations.

Table 7. Social value generated through employment during the 5 years of dam construction (source: created by authors).

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[1] Ministry of Government. "Resolution of the Council of Representatives of the National Commission on Minimum Wages," Federal Official Register (DOF). 1 January 2017.
Original: Secretaría de Gobernación - Diario Oficial de la Federación: Resolución del h. Consejo de Representantes de la Comisión Nacional de los Salarios Mínimos, 1ro de enero de 2017.

[2] See www.wordsalaries.org/.

[3] See http://www.tradingeconomics.com/mexico/wages.

Average, low and high estimates	Number of Full Time Equivalent Jobs	Monthly Salary	Total Value	Local Value
Average value estimate of job creation (average salary for construction site, 2005)	14,000	3,918	658,224,000	460,756,800
Low value estimate of job creation (minimum wage in Mexico, 2017)	14,000	1,680	282,240,000	197,568,000
High value estimate of job creation (living wage in Mexico, 2017)	14,000 direct jobs remunerated with maximum wage + 14,000 indirect jobs remunerated with average salary	4,955	1,490,664,000	1,043,464,800

2.8.2 Sacred Sites

In the area planned to be flooded for dam construction there are at least 14 registered sacred sites of high importance for the 14,800 people of the indigenous Náyeri and Wixárika cultures (AIDA, 2014); the majority of these sites are not publicly known, and known only to members of the indigenous communities that use them (NUIWARI, personal communication, July 2017). The loss of these sacred sites, including the San Pedro River as a divine entity within their worldview, would have a significant impact on their mental, physical, and emotional health, as well as on the permanence of these communities, for whom these sites make up part of their cultural roots and are fundamental in their everyday lives and relationship with nature (NUIWARI, personal communication, July 2017; AIDA, 2004; CFE, 2014).

The economic valuation of important cultural sites, and in particular those with spiritual significance (sacred sites), is difficult because their estimated monetary worth will not capture their real value for the people who benefit from their existence. Some studies, though, have reached an estimation of the cultural value of sacred sites by valuing the mitigation costs of impacts on the emotional and physical health of the affected communities. The International Institute for Sustainable Development (IISD, 2008) valued mitigation costs for Canadian indigenous communities of the Pimachiowin Aki area: they estimated the costs of traditional healers (equivalent to a medical psychologist) in giving support to communities in the process of losing their sacred sites; this valuation indicated an equivalent of 31.5 CAD/person/year in affected communities.

Valuation of the sacred sites that would be flooded for the Las Cruces hydroelectric project was calculated from mitigation costs of psychological support for the communities in response to the loss of their sacred sites along the San Pedro River. The costs of psychological support were estimated based on a per-session rate with private practitioners from Mexico City; the estimated minimums, maximums, and averages that were used in the model were 500 MXN, 2,500 MXN, and 800 MXN per session, respectively. Data on the costs of psychological support in the public sector were researched; however, it was observed that real costs are not reported and the data adds costs and subsidies. Although mitigation costs may be overestimated because of the difference in rates between Mexico City and the state of Nayarit (Nayarit rates are unknown, but it was assumed they are lower), the calculations did not include additional transport, lodging, and food costs for psychologists. The average mitigation cost for providing therapy to all members of the communities once a week for the 20-year span of the project was estimated at 332.8 MXN per person and per year, reaching an average annual value of 4.9 MDP and total costs of 98.5 MDP.

2.8.3 Population Displacement

Construction of the dam would affect 66 people who currently live in the area that would be covered by the reservoir (CFE, 2014). It was assumed that the social economic cost of displacing the local population included compensation costs, both for new housing construction and for losses in economic livelihood. Furthermore, the mitigation costs of psychological effects were also included (Cernea, 1997). The impact of the displacement of the affected population was calculated based on incurred costs according to market prices. The average total values included in the valuation of displacement incorporated 15.2 MDP in housing construction (66 houses estimated at 230,000 MXN each), 31 MDP in compensation for livelihood loss spanning 10 years, and 439,296 MXN for weekly psychological support for each of the 66 people affected during the project's 20-year duration (the initial five years of construction were not included), resulting in a total cost of 46.6 MDP.

Other effects of constructing the hydroelectric project, and subsequent displacement of populations affected by the creation of a reservoir, that were not valued in this study include: a) changes in mobility or transportation of these communities and future costs of mobility imposed by the reservoir, b) decline in grasslands for the communities' livestock pastures, which entails social conflicts between communities for land use, and c) the privatization of certain natural resources that are currently considered freely accessible through the river, and with the construction of the dam will cease to be so (SuMar - effects on Náyeri communities).

2.8.4 Tourism

Information on tourism in the study area was scarce, and the main sources of information were obtained from documents about a market analysis for tourism development in the entire Marismas Nacionales area (SuMar), from data included in a valuation analysis of ES in Marismas Nacionales (Akker et al., 2012), and from personal communication with the director of the Marismas Nacionales PA (Víctor Hugo Vásquez Morán, director of the PA, July 2017). The following information is qualitative, and the results were not included in the quantitative model. The PA has tourism value, but it is not a developed sector. Evidence indicated that the majority of people that visit the coastal area are local or regional (from the cities of Tepic, Guadalajara, Mazatlán, and the closest municipalities) and seek oceanside activities. The visitors that reach surrounding areas or enter the RBMN (between 30,000 and 40,000 people a year) also seek out beach and ocean activities, and approximately half visit the island of Mexcaltitlán, an important place for Mexican culture (personal communication with the director of RBMN, July 2017). Based on the information obtained, no direct connection was found between tourism in the area and the biodiversity of the Marismas Nacionales PA.

The value generated by tourism in the area of Marismas Nacionales was calculated using travel cost methodology. The average cost per person of what a visitor pays for spending a day in Mexcaltitlán was calculated, including land transport, two boat trips for accessing and leaving the island, food, and beverages. Visitors that go to the island were the only ones considered (17,500 people a year), because there is no evidence that others enter the PA; infrastructure services focused on nature and/or adventure tourism were also not found in the PA. The calculated cost per person per trip is of approximately 562 MXN; generating a total annual value of 8.6 MDP derived from present tourism in Marismas Nacionales.

The potential value of future tourism in the PA was calculated by taking into account the area's potential as a tourist destination and incorporating the most recent market analysis estimates for Marismas Nacionales. There is market potential for 2.76 million people in the region who could potentially visit the PA based on socioeconomic characteristics described by SuMar. If 20% of this market visited the PA and was willing to pay 985 MXP per person per trip (two days), the potential value of future tourism could be 543 MDP per year. This is assuming that optimal infrastructure and services for this market are developed and compatible with PA conservation. It is possible for this value to be geographically concentrated in the reserve's outer areas, Bocas del Camichín, Escuinapa, and Tecpan, since these are the entrance points to the reserve, and only a small portion of the value generated would be distributed to other populations in the San Pedro watershed.

Even though changes to ecosystems as a result of dam construction could be significant, these are not seen as directly linked to the impact on present or future tourism. There are currently other factors that play a more relevant role for tourism (e.g., security, infrastructure and services, and accessibility) than the biodiversity and ecosystems present in the area. A loss of tourism could be valued in a scenario where the impacts of the dam project provoked a total collapse of coastal wetlands in the area (future potential value); however, this scenario is highly unlikely under current conditions.

2.9 Direct Impact of the Project

This section describes the direct impacts of the project. These include:

- Land occupied by the reservoir and a loss of ES
- Greenhouse gas emissions from the reservoir
- Greenhouse gas emissions from materials used in dam construction (retaining wall)

2.9.1 Land Occupied by the Reservoir

The land that would be occupied by the reservoir, as well as the area that would be modified by the construction of project access points and infrastructure, are for the most part areas covered in forest. The communities that inhabit the region do not use these for productive purposes, except for a small fraction. The flooding caused by the dam would affect an area equal to 5,493 ha (CFE, 2014) (Table 8). The forests destined for flooding can be valued based on the ES that they provide, such as water supply and filtration, carbon capture, erosion control, and primary material production, among others. The specific ES of these forests were not evaluated in detail, and in this case a value transfer was made to estimate their value based on the results that De Groet et al. (2012) published in regard to forests, which indicate a value of 26,057 MXN/ha, generating a total loss of 2.7 BDP.

Table 8. Description and area required for construction of the Las Cruces hydroelectric project (source: CFE, 2014).

Entire Area Required for Project and Description	Hectare (ha)
Project work (polygon 1)	291.42
Project access from the left side (polygon 2)	444.75
Project access from the right side (polygon 3)	10.91
Regime Dam work areas (PCR)	158.14
Dam surface	4,506.14
Dam PCR	81.9
Total area	5,493.26

2.9.2 Greenhouse Gas Emissions from the Reservoir

All reservoirs emit greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) as a result of the decomposition processes of organic materials that come from the vegetation at the bottom of the reservoir. The quantity of released gases varies depending on various factors, including climate, reservoir surface area, etc. Deemer et al. (2016) provide a global synthesis of reservoirs that was used for the Las Cruces analysis. The emissions addressed in this study vary between 47 gCO_2-eq/kWh and 128 gCO_2-eq/kWh (the average value is 88), which is a conservative estimate compared to other publications that mention 2,000 gCO_2-eq/kWh for reservoirs in tropical regions. The average carbon price value used was 78 USD/ton/CO_2-eq (PwC, 2015).

The annual value of greenhouse gases emitted by the reservoir is 84.3 MDP, which generates a total value of 1.7 BDP.

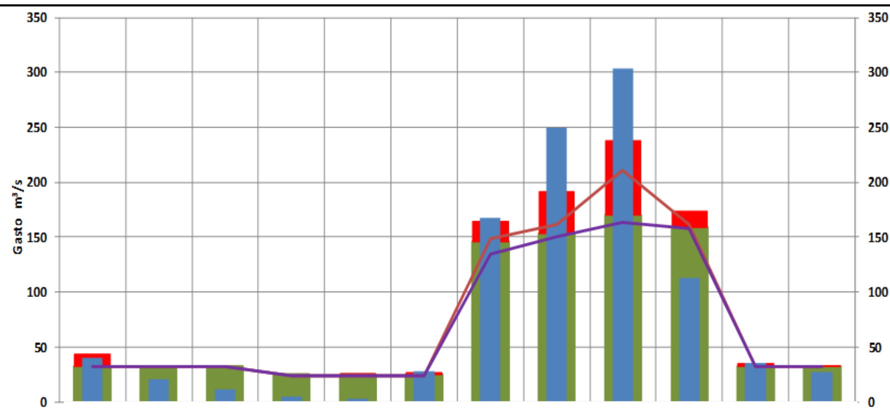
2.9.3 Greenhouse Gas Emissions from Materials Used in Dam Construction (Retaining Wall)

The construction of the hydroelectric project utilizes a large quantity of material, particularly concrete; this employs cement, which requires an intense amount of energy for its production. Any economic activity creates an environmental impact throughout its life cycle, from the production of primary materials, to their distribution and processing. These environmental impacts are varied and encompass climate change, water pollution, water consumption and scarcity, soil depletion, air pollution, and toxic fallouts, among others. In this study, climate change was considered by examining GHG emissions resulting from the production lifecycle of the construction materials of the dam, particularly concrete.

The dimensions of the Las Cruces dam span 830 m in length, 188 m in height, and 8 m in width, so that the dam's total construction requires more than 880,000 m^3 of concrete, which constitutes more than 2 million tons of concrete. The average GHG emissions derived from concrete are 61 gCO_2-eq/t of concrete, which can vary depending on different parameters like energy use and exact mixture ratios (Ecoinvent, 2017). In all, total GHG emissions from the Las Cruces hydroelectric project would cost 160 MDP.

2.10 Changes in Flooding Regime

The data for changes in the river's hydrologic regimes was provided by the CFE; the annual natural fluctuation of the river (blue) and its modification from the functioning of the dam (green) are shown in Figure 14. In the month of September, the month with the greatest water volume during the rainy season, a change of 303 m^3/s to 170 m^3/s can be seen (CFE, 2014). The hydraulic model used in this study focused on analyzing changes in the river's flow volume during the rainy season, which is the period with the greatest variation in the river's hydrologic regime.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Turbine hours	4	4	4	3	3	3	18	19	21	20	4	4
Median monthly river flow before construction of the Las Cruces dam	40	21	11	5	3	28	167	250	303	113	36	27
Average monthly river flow changes seen with an operational dam (PCR)	32	32	32	24	24	24	145	153	170	159	32	32
Average monthly river surge caused by the operational dam (PCR)	11	0	0	0	0	3	19	38	68	15	2	1
Average maximum monthly river flow during PCR operation	32	32	32	24	24	24	148	162	211	162	32	32
Average minimum monthly river flow during PCR operation	32	32	32	24	24	24	135	151	163	158	32	32

Figure 14. Expected monthly flow-rate changes of the San Pedro River as a result of the Las Cruces dam (source: CFE, 2014; translation done by authors).

The Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic and flooding model developed by the United States Department of Defense was used to analyze potential changes in the flooding regime of the San Pedro River watershed as a result of dam-induced variations in river water volume.

The basic cartographic information used as input (e.g., watershed maps, topography, etc.) is the same as that used in delimitating the study area; in this case, the watershed delimitation developed by INEGI. The hydrographic layer was overlaid onto the digital elevation model, and average measures in width and depth of each of the rivers were applied according to their order of magnitude (Table 9), given that the digital elevation model does not incorporate bathymetric data.

Table 9. Hydrologic estimates used in the hydraulic model (source: created by authors).

Estimates Used for Width and Depth		
River Order of Magnitude	**Width (m)**	**Depth (m)**
0–1	2	1
2–3	4	1
4–7	20	2
River's principal channel	50	2

The dimensional hydraulic model incorporated the watershed area into the analysis, from the point of dam construction to the coastal floodplain, including data on land cover and water movement due to surface friction. A Manning coefficient was determined for each category of vegetation land cover.[4] The model was run constantly for periods of four months to one year, and the simulations calculated changes before and after the dam during the rainy season (July to October) and the dry season (November to June). The following variations in water flow were applied, accounting for the month with the highest (September) and lowest (May) precipitation according to estimates made by the CFE: 3 m^3/s and 24 m^3/s for the dry season with and without the dam, and 170 m^3/s and 303 m^3/s for the rainy season with and without the dam. The data generated is the result of computing different variables (e.g., gravity, friction, and water movement) and hydraulic equations throughout the study area. The model outcome indicates water levels, flood area limits, and water depth and velocity at any given moment or location during the simulation. Cross-validation of the hydraulic model outcomes with information on land cover and municipal delimitations indicated values pertaining to the flood zone extension (ha) and the minimum, maximum, and mean depths for each category.

The model results identified vulnerable areas with flooding potential (flood increase), as well as areas that would cease to flood (dry zones) as a result of changes in river water flow caused by the dam (Figure 15 and Figure 16). Because of the imprecise nature of the data available for running the model, the outcomes cannot be considered an exact simulation of what could happen, but an approximation instead, thus emphasizing their interpretation as areas vulnerable to change. Precise bathymetric information about the watershed would be necessary to create a more exact scenario.

Another important factor to keep in mind regarding the presented outcomes is the fact that the model solely deals with changes in water flow owing to the dam; it excludes the effects of water extraction for irrigation or other purposes, as well as structures for flood protection in or around urban zones. The total change in surface area that would cease to flood is 4,289 ha. The model's quantitative results are based on the type of land use (e.g., farmland, wetland) and on the surface area of land comprising the four municipalities that share the San Pedro River section that would undergo changes in flooding regimes derived from the hydroelectric project.

[4] See "Manning Coefficient," http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm.

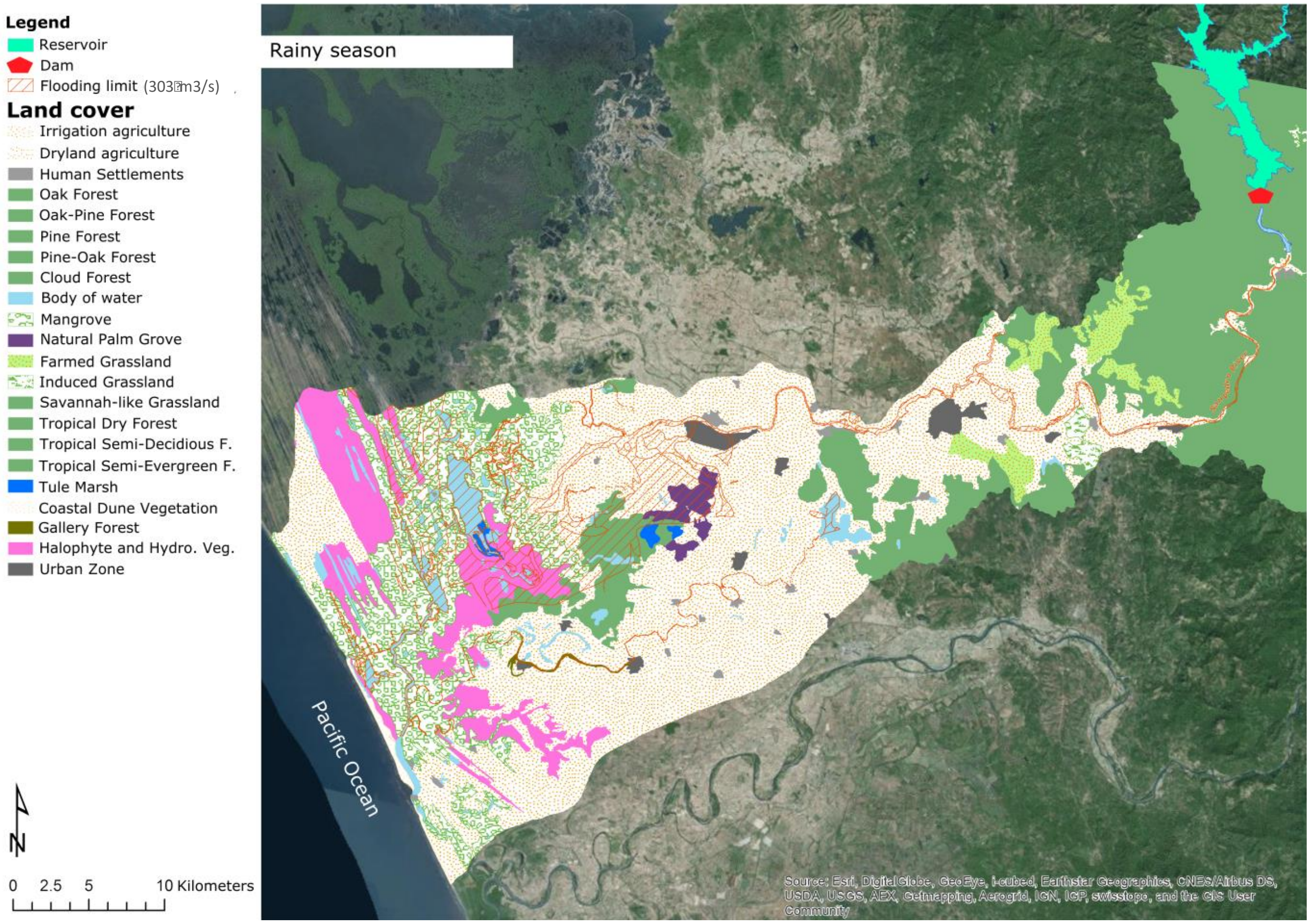


Figure 15. Lower area of the San Pedro River watershed vulnerable to flooding during the rainy season with natural hydrologic regimes (303 m^3/s) (source: created by authors).

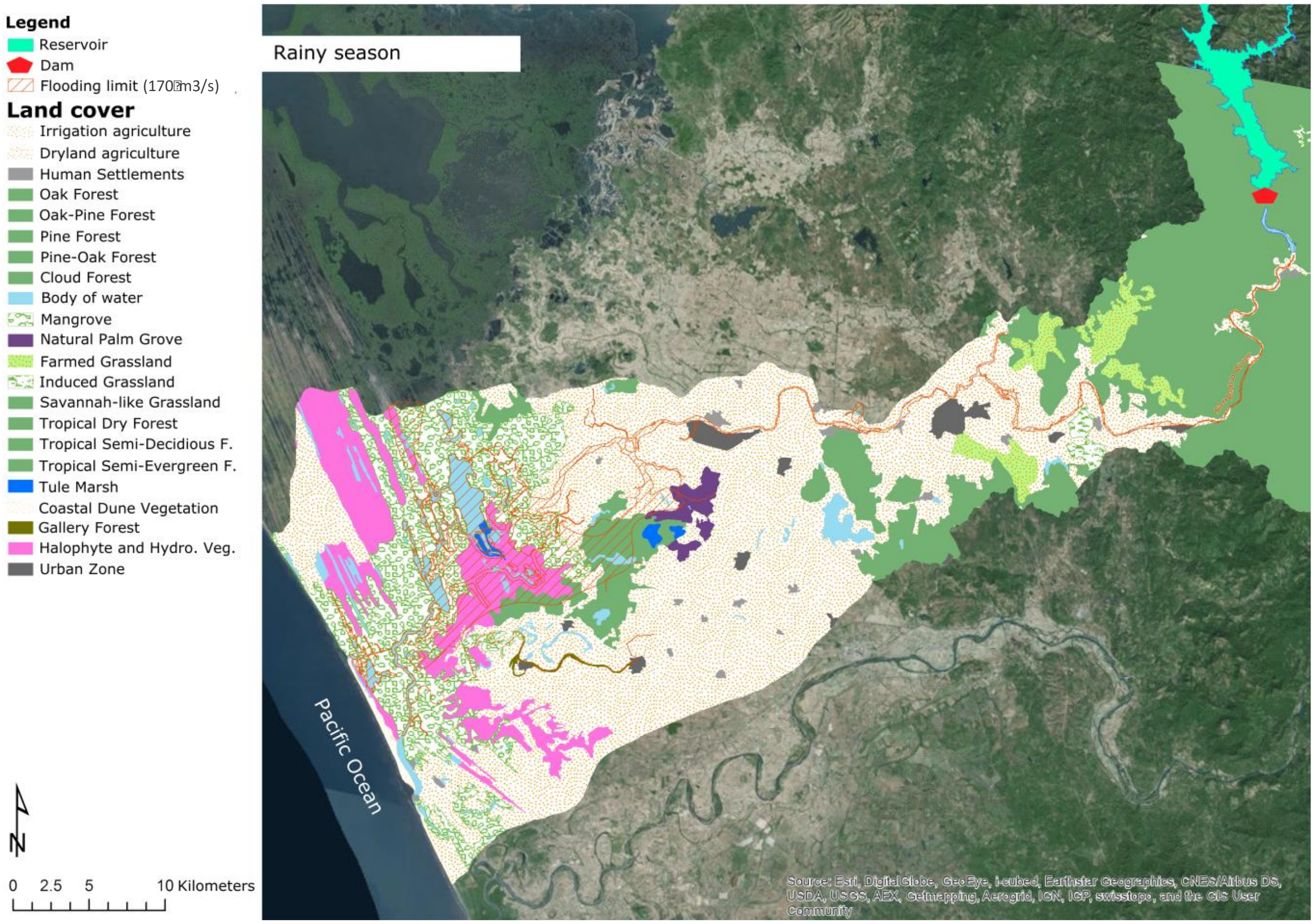


Figure 16. Lower area of the San Pedro River watershed vulnerable to flooding during the rainy season with hydrologic regimes modified by the Las Cruces dam (170 m^3/s) (source: created by authors).

A decline in the flooding regime will probably transform the wetlands of the lower watershed into another type of ecosystem, therefore modifying the ES that they provide to society. It is important to note that wetlands are one of the most diverse and rich ecosystems in terms of ES provision, which means that their loss or transformation implies a deterioration or total loss of their functions.

The following outcomes are derived from possible changes to ES provided by wetlands and farmlands, estimating that 2,257 ha of mangroves and 916 ha of farmed land will not be flooded by the new flooding regimes. The valuation of agriculture was estimated on the basis of its productivity and the wetlands were valuated on the basis of certain ES:

- Water quality
- Biodiversity and habitat
- Carbon capture and storage
- Fisheries

2.10.1 Water Quality

Wetlands are ecosystems with great capabilities for filtering and improving the quality of water that passes through them. A decline in the area covered by wetlands—which would cease to be subject to seasonal flooding from the river during the rainy season—implies a change or transformation of the ecosystem into habitats less dependent on flooding dynamics typical to mangrove forests, and therefore a decline in nutrient filtration functions. This is why the study did not estimate a total loss of the service, but rather a decrease in its value.

The valuation of the study area's water filtration service was done by value transfer, since generating primary data related to local ES was beyond the scope of this study.

Based on the results of various meta-analyses of the value of nutrient filtration in wetlands and mangroves, minimum and maximum average estimates were utilized between 443 MXN/ha (Brander, 2006) and 673 MXN/ha (Salem, 2012), and an average of 558 MXN/ha was employed. It is important to mention that these estimates are an average of the value of this ecosystem service, and depending on the type of wetland, its condition, and its location, the value of nutrient filtration can reach 114,862 MXN/ha (Brander, 2006). The value of nutrient filtration services provided by tropical forest ecosystems, considering ecosystem replacement, was estimated to be 49 MXN/ha according to the reports of De Groet et al., (2012).

After incorporating the results of the hydraulic model regarding the extension of wetlands in the study area (a total of 2,257 ha including mangroves, 82.6%, halophyte vegetation, 16.5%, tule plants, and gallery forest, <1%) vulnerable to changes in flooding regimes caused by the dam, annual losses were estimated at 1.26 MDP and a total value of 25.2 MDP.

2.10.2 Biodiversity / Habitat

Changes in biodiversity and habitat were estimated based on the San Pedro River lower watershed wetland areas that would no longer be flooded by the river because of the dam, i.e. a reduction in the river's size. The value of wetlands related to their function in maintaining biodiversity was estimated from a meta-analysis value transfer, in which minimum, maximum, and average values were reported of 246 MXN/ha (Salem, 2012) and 853 MXN/ha (Brander, 2006), with an average of 550 MXN/ha. The literature indicates that the values of this service, in specific cases, can exceed more than 1.6 MDP/ha.

The annual losses in biodiversity associated with wetlands in the study area were estimated at 1.24 MDP, with a total value of 24.8 MDP. In this case, in its function in maintaining biodiversity, ecosystem replacement was not considered; in other words, the ES was deemed totally lost. Not only are there marked differences in the biodiversity that various ecosystems maintain, there are also differences in the people's willingness to pay to observe and experience different habitats.

2.10.3 Carbon Capture and Storage

The capacity for carbon capture and storage is directly related to the type of ecosystem. The dam-driven change in flooding regime is expected to directly affect the wetland ecosystem of the lower San Pedro River watershed, possibly reducing its breadth. The changes were valued based on the reduction of wetland area indicated by the model, and on the shift from wetland ecosystem to a type of tropical forest. This in turn reduces the area's function in capturing and storing carbon.

Calculations of estimates in this study incorporated the average values of carbon sequestering reported for Marismas Nacionales, 8 tC/ha/year (Akker et al., 2012), and an average carbon storage value of 600 tC/ha (Bhomia et al., 2016). Ecosystem change from variation in flooding regimes represents the difference in carbon capture and storage between wetlands and the replacement ecosystem. The replacement ecosystem is expected to be a type of tropical forest, with an estimated value of 33,540 MXN/ha based on a publication by De Groet et al., (2012). This value includes the cost of carbon.

The minimum and maximum values of the study area's wetland carbon capture and storage function, employing an average carbon price of 78 USD/ton/CO_2-eq (PwC, 2015), were estimated at 50,274 MXN/ha and 335,162 MXN/ha respectively, with an average value of 130,713 MXN/ha. The model-based results indicated losses of 295 MDP per year and a total loss of 5.9 BDP.

2.10.4 Fisheries

Local fishermen use the coastal wetlands of the lower San Pedro River watershed, including the RBMN, because of their richness and high productivity associated with the mangroves. The total value of these Marismas Nacionales fisheries was estimated at 178.3 MDP (Akker et al., 2012). The potential loss of the production function associated with these fisheries and the network of coastal wetlands was estimated based on the linear relationship between the actual value of production and the total area (200,000 ha) that sustains production. In practice, it is the border or edge of the mangroves closest to a body of water that generates the greatest service for fishery productivity; however, it was not possible to base model calculations on this parameter.

The value per hectare of fisheries associated with mangroves in the study area spanned from 0 MXN/ha to 615,334 MXN/ha (Danemann et al.). It was assumed that if the effect of flooding impacts an area of wetland that has no connection to the wetland's bodies of water, the value of loss is zero, while the maximum value corresponds to the study done by Pronatura Noroeste, A.C., in which the value of 615,334 MXN/ha refers to the productivity associated with the mangrove edges in direct contact with marine/lagoon bodies of water. The estimate made by Akker et al. (2012) of 886 MXN/ha was taken as the average value.

Based on the model and estimates generated, the changes in the flooding regime could provoke annual loss for the fishing sector of 2 MDP and a total loss of 40 MDP.

2.10.5 Agriculture

The farming area of the lower part of the watershed, below the dam, spans 271,000 ha. Agriculture (dryland and irrigated) is one of the most important economic activities in the study area, as it constitutes the livelihood of the majority of the local population. Fifteen percent of national rice production is cultivated in the San Pedro River watershed (FONNOR—Coastal Watersheds and Climate Change[5]). The San Pedro River flooding regime is crucial for local agriculture, as the flooding brings sediments that nourish the soil, maintaining its productivity.

The results of the model indicate a 916 ha reduction in farmland areas subject to flooding. This calculation probably underestimates real farmland area, given that satellite images show a larger area, most likely reflecting the most recent expansion of these activities; however, the available data in INEGI's geographic information system, from where the area extension by crop and economic value is obtained, shows a smaller area.

Table 10 shows detailed results from the model for agriculture. The productive value of crops according to municipality was also included, drawn from data published by INEGI in 2014. On average, the productive value of farmland within the lower San Pedro River watershed is 15,930 MXN/ha.

Table 10. Expected changes in farmland arising from changes in flooding regime (source: created by authors).

Municipality	Flooded area before construction of the dam (ha)	Flooded area after construction of the dam (ha)	Decrease in previously flooded agricultural area (ha)	Decrease in previously flooded agricultural area (%)	Productive value of land (ha)
Rosa Morada	4,874,106	4,664,003	21	17.6 %	27,936
Ruiz	4,488,770	3,952,188	54	16.2 %	30,888
Santiago Ixcuintla	9,754,874	8,981,538	77	99.1 %	41,588
Tuxpan	22,979,323	15,339,019	764	132.0 %	27,028
Total/Average	42,097,073	32,936,748	916		15,930

For the analysis, it was assumed that the reduction in nutrients and sediments carried by flooding caused a decline in soil fertility and land productivity of 10% (minimum), 50% (maximum), and 30% (average).

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[5] FONNOR. "Project on Coastal Watersheds and Climate Change," http://www.c6.org.mx/cuencas-costeras/localizacion-de-las-cuencas/.

2.11 Changes in sediment regime

The San Pedro Mezquital River's natural flow carries sediment down from the highest point of the watershed to the coastal plains and the river mouth in the coastal wetlands of Marismas Nacionales. The transportation of sediment is of great importance to the ecosystem, to the local communities at the lowest part of the watershed, and to their economy. The sediment that is deposited and transferred there maintains the local farmlands fertile and keeps the ecosystems productive. Furthermore, the deposited sediment helps maintain the coastline facing the Pacific Ocean.

To understand the sediment transportation dynamic of the San Pedro River watershed, it is important to identify its origin. The Invest model sediment analysis indicates that approximately 26,844,900 t/year of sediment are generated in the highest portion of the watershed and are transported by the river to its lower segments. From there, 90.7% (24,360,383 t/year) makes it to the middle section of the watershed where the Las Cruces dam would be built. The CFE indicates that the amount of sediment present at the dam site would be around 19,776,382 t/year (assuming a density of 1.5 g/cm^3). Passing the dam, sediment deposition is minimal.

One of the direct effects that dams have on watersheds is sediment retention. Its efficiency can vary from one dam to another, depending on various aspects, among them reservoir size, shape, and depth, its wall height, and the sediment volume that makes it to the reservoir. The following Brune formula (1953) was used to calculate the sediment retention efficiency in Las Cruces:

$$E = 100 \cdot \frac{\frac{C}{I}}{0.012 + 1.02 \cdot \frac{C}{I}}$$

E: retention efficiency: %

C: reservoir storage capacity: 2.3 billion m^3 (SEMARNAT, 2014)

I: annual river flow reaching the dam: 2.6 billion m^3/year (CFE, 2014)

The results report a 96.7% sediment retention efficiency rate. The CFE estimates a retention volume of 19,123,761 t/year. Sediment retention by the dam would affect the natural river sediment regime, resulting in a net loss of sediment deposition along the coastline, leading to its erosion. This effect has been widely studied and documented as a direct consequence of sediment retention by hydroelectric reservoirs around the world (Anthony, 2015). The Akosombo dam over the Volta River in Ghana has caused the yearly erosion of approximately 10 to 15 meters of Togo and Benin beaches (McCully, 2001). One of the most dramatic examples is the effect dams have had on the Nile River, which has seen a land loss of 125 to 175 meters per year (Rozengurt and Haydock, 1993). The construction of multiple dams on the Santiago River watershed adjacent to the San Pedro River has caused land loss at the river mouth estimated at 16 m/year (Del Castillo, 2011 and Akker et al., 2012).

Marismas Nacionales receives approximately 3,907,500 t/year of sediment (CFE, 2014). Of this volume, 90.7% would come from sections of the watershed above the Las Cruces dam. There would be a reduction in the amount of sediment reaching Marismas Nacionales of 3,427,147 t/year because of dam retention. Given the geography of the watershed, the fact that the river mouth is in the Marismas Nacionales wetlands and not directly open to the sea, and the deposition of sediment along the coastal plains, it was estimated that only 10% of the sediment volume (a conservative estimate) reaches the coastline, while the majority of the sediment stays in the internal sections of the wetlands. This estimate was made incorporating the published work of Berkun (2012), whose findings indicate that the average amount of sediment to find its way to the coastline through various rivers ranges from 20% to 50%. The decline in sediments that make up the coastline in the San Pedro River watershed would be 342,715 t/year. Assuming the San Pedro River watershed influences the sediment deposition dynamic along the 26.4 km coastline, and that the coastline is expected to recede when the eroded section reaches 1 meter in depth, it is estimated that there would be a loss of coastline of 22.8 ha/year, and 8.6 m/year (inland).

For the following chapters, a 22.8 ha/year loss was assumed, with values correlating farmland and ES generated by coastal wetlands. Along the Pacific coast of the San Pedro River watershed, two thirds of its length are made up of farmlands, while a third is coastal wetlands. Agriculture valuation was estimated by productivity, while wetlands were valued using certain ES:

- Water quality
- Biodiversity and habitat
- Carbon sequestering and storage
- Fisheries
- Protection against extreme weather events

2.11.1 Water Quality

In order to calculate the loss of nutrient filtration due to coastline erosion, the same model was used that is described in section 2.10.1, including references to determine minimum, maximum and average values. In this case an ecosystem replacement was not considered since there was a net loss in the extension of the wetlands. Taking into account that the loss of land from changes in sediment regime caused by the dam would be 7.6 ha/year (corresponding to one third of the coastline), the average losses related to filtration services would be 607 MXN/ha, 4,624 MXN/year, and a total value of 971,001 MXN.

2.11.2 Biodiversity and Habitat

The loss of biodiversity and habitat were estimated using the model described in section 2.10.2, including references to determine minimum, maximum and average values. Taking into account that the loss of land from changes in sediment regime caused by the dam would be 7.6 ha/year (one third of the coastline), the related average losses are 263 MXN/ha, 1,999 MXN/year, and a total value of 419,892 MXN.

2.11.3 Carbon Capture and Storage

The same estimating principals were used as described in section 2.10.3, including references to determine minimum, maximum and average values. In this case a net loss in function was assumed, not a change in ecosystem. If the loss of land from changes in sediment regime caused by the dam would be 7.6 ha/year (one third of the coastline), the average loss related to carbon capture and storage were calculated to be 178,332 MXN/ha, 1,358,152 MXN/year, and a total value of 285,211,955 MXN.

2.11.4 Fisheries

The same model was used that was described in section 2.10.4, including references to determine minimum, maximum and average values. If the loss of land from changes in sediment regime caused by the dam would be 7.6 ha/year (one third of the coastline), the average loss for local fisheries would be 886 MXN/ha, 6748 MXN/year, and a total value of 1,417,137 MXN.

2.11.5 Agriculture

The possible expected changes due to sediment retention by the Las Cruces dam are based on the estimated loss of land that is currently being used as farmland in the Santiago Ixcuintla municipality. Based on land loss of 15.2 ha/year (corresponding to two thirds of the coastline), average estimated agricultural losses would be 20,794 MXN/ha, 316,728 MXN/year, and a total value of 66.5 MDP.

2.11.6 Protection against Extreme Climate Events

The erosion of the coastline would not only impact the ecosystems, it would also make the local communities situated near the Pacific coast of the San Pedro River watershed more vulnerable. According to population data from INEGI (2010) and imaging of the coastline from Google Earth, an estimated 500 people live within the first 500 m inland (**Error! Reference source not found.**). The analysis takes into account the cost of extreme weather events (such as hurricanes), based on losses that would affect vulnerable communities and their economic activities (agriculture and fishing). The valuation was based on the cost of property damages and diminished farmland and fisheries productivity as a consequence of hurricanes every 5.3 years (Akker et al., 2012), assuming that for each climactic event, half of the properties and production activities suffer losses.

Property damages were calculated assuming each dwelling houses three people, meaning for each extreme weather event 166 dwellings would suffer damages (the replacement cost would be 229,724 MXN per dwelling). Agricultural losses were based on productivity values corresponding to the Santiago Ixcuintla municipality, for the fisheries the same value per hectare was used that was described in section 2.11.4.

The results of the model indicated total losses of 95.9 MDP over a 20-year span and four hurricanes during that time.

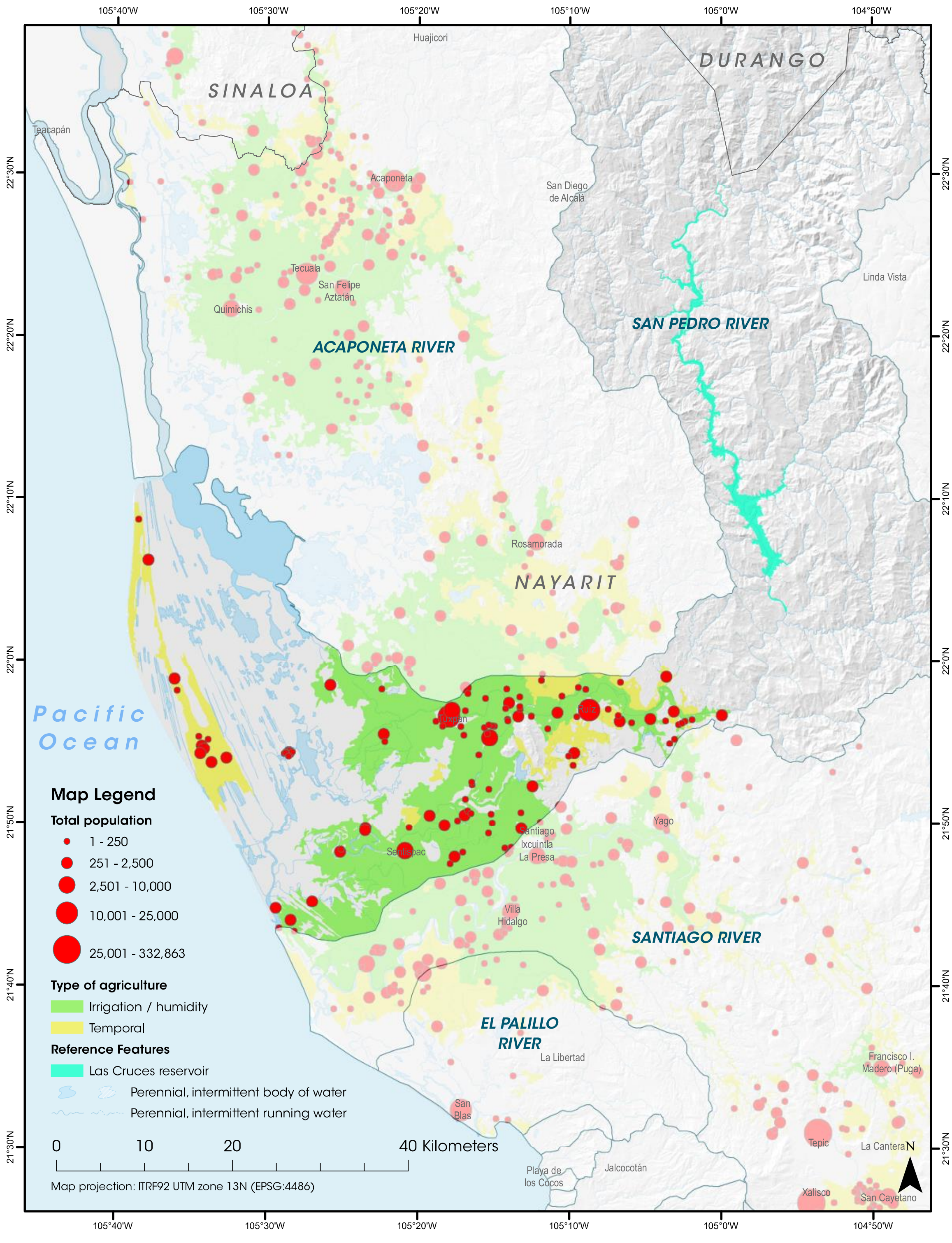

Figure 17. Distribution of human population and agricultural lands of the lower watershed of the San Pedro River.

2.12 Financial Analysis

2.12.1 Cost of the Las Cruces Hydroelectric Project

The construction costs projected by the CFE for the Las Cruces Hydroelectric project are 10.49 BDP (639.6 MUSD); however, cost overruns of a project of this type are possible. The most recent studies indicate that on average, hydroelectric project cost overruns are from 70% to 90%[6]. In addition, operational and maintenance costs are estimated at 2.2% of the costs of the project capital (IRENA, 2012) which are typically not announced in the project public communications.
Using the costs estimated by the CFE, the total cost of the project during the period analyzed (25 years) was estimated to be 11.3 BDP (690 MUSD); if the scenario includes a 70% increase in budget, the total cost would reach 19.3 BDP (1.17 billion USD).

2.12.2 Project Value of Electricity and Net Social Cost

Energy production through hydroelectric dams plays an important role in electricity supply regulation, particularly during peak consumption hours, due to their rapid generation of electricity compared to other sources of electricity like thermoelectric and nuclear plants. As a result of their short-term generation capacity, hydroelectric dams have slightly different functions than other production units. In the case of Las Cruces, annual production of electricity would be approximately 751 GWh.

To calculate the project's revenue, the costs of electricity production in the country for the first half of 2016 were taken as reference points, which varied between 787.6 MXN/MWh and 984.5 MXN/MWh[7]. If part of the energy generated by the dam would be supplying the demand for electricity during peak hours, the study estimated that the selling price of electricity would be in the highest range for the region of Nayarit (935.3 MXN/MWh). The project's generated revenue was multiplied by 16.6 years since, though the time horizon analyzed for the project was 25 years, during the first 8.4 years the dam would not be capable of producing electricity, thus generating no revenue. As previously mentioned, CFE has estimated that the first 5 years of the project would be dedicated to dam construction; however, the minimum time necessary for filling the reservoir is 3.4 years. This period was calculated based on the volume of available water, additional to the water the dam would be releasing during the rainy season in a normal year of operation (above 662 hm^3/year).

The financial perspective previously described is not the same for 2017, given recent changes in the Mexican electricity sector that, through market liberalization, has resulted in a price drop. The most recent contracts for supplying electricity demand for the next 15 years were tendered

[6] Sovacool et al. and https://www.sbs.ox.ac.uk/school/news/press-office/press-releases/large-hydro-electric-dams-unviable-andseriously-damaging-emerging-economies. 2014
[7] US Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=26932#

in September 2016, and this process had widespread participation by bidders, with average prices of 541.5 MXN/MWh, which were 30% lower than those of the first half of the year. The expected revenue of Las Cruces, negotiated with the most recent average selling price, could decline further in the future with recent changes in legislation. Using this selling average, total hydroelectric dam revenue (in 16.6 years) would fall to 6.7 BDP, a lower quantity than the projected investment costs according to CFE (10.49 BDP). The return-on-investment threshold (economic equilibrium) of Las Cruces, including investment in capital and operational and maintenance costs, would require an electricity selling price of 909 MXN/MWh[8]. In addition, the construction costs of the dam are expected to surpass the initially set cost. As already mentioned, the most recent studies indicate that on average, cost overruns of hydroelectric projects are from 70% to 90%[9].

Construction costs projected by the CFE (10.49 BDP) as well as the most recent electricity price (542 MXN/MWh) were used as the basis for financial analysis in average conditions; for minimum estimates, the same construction cost and the highest rate for the Nayarit region (935 MXN/MWh) were used; and in estimates with maximum values, the construction cost of the project increased to 17.8 BDP (70% cost overrun) using the most recent rate (542 MXN/MWh). The projected cost of construction was divided between the first five years, and 2% annual operational costs were calculated out of the total cost of the project.

3 Results and Discussion

3.1 General Results

The cost-benefit analysis of the project, derived from the presented model and analysis, demonstrated a net social cost for Mexican society of 15.3 BDP in a time horizon of 25 years. Detailed results are shown in Table 11 (first column, average estimates) and Figure 18, where sensitivity analysis results (low and high values) are also provided for each of the component assessed. Impacts assessed were divided in: 1) direct impacts on local communities from benefits like job creation, and costs in population displacement and loss of sacred sites, 2) impacts derived from project construction in the watershed (carbon footprint of construction, GHG emissions from the reservoir, and loss of ES from flooded, land ecosystems), 3) changes in flooding regimes, 4) changes in sediment regimes, and 5) financial results.

[8] Estimated costs of Project according to CFE: 639.6 MUSD (10.49 BDP); operation and maintenance costs estimated at 2.2% of project capital costs according to IRENA, 2012

[9] Sovacool et al. and https://www.sbs.ox.ac.uk/school/news/press-office/press-releases/large-hydro-electric-dams-unviable-andseriously-damaging-emerging-economies. 2014

Table 11. Analysis of social cost of the Las Cruces hydroelectric project (source: created by authors).

		Average estimates	Low estimates	High estimates	Low estimates (relative change to mean)	High estimates (relative change to mean)
		MUSD	**MUSD**	**MUSD**	**%**	**%**
Social impacts	Jobs	40	91	17	226%	43%
	Sacred sites	(6)	(4)	(19)	63%	313%
	Displaced population	(3)	(3)	(3)	100%	102%
Impact of project	Land covered by reservoir	(166)	(83)	(209)	50%	126%
	Reservoir's emissions	(103)	(21)	(385)	21%	374%
	Dam's construction carbon footprint	(10)	(4)	(25)	38%	256%
Flooding regime	Water quality	(2)	(1)	(2)	79%	121%
	Biodiversity/habitat	(2)	(1)	(2)	45%	155%
	Carbon storage and sequestration	(360)	(138)	(922)	38%	256%
	Fisheries	(2)	-	(1.693)	0%	69’444%
	Agriculture	(12)	(4)	(20)	33%	167%
Sediment regime	Water quality	(0)	(0)	(0)	81%	119%
	Biodiversity/habitat	(0)	(0)	(0)	45%	155%
	Carbon storage and sequestration	(17)	(7)	(45)	38%	256%
	Fisheries	(0)	-	(60)	0%	69’444%
	Agriculture	(4)	(4)	(4)	100%	100%
	Extreme events protection	(6)	(6)	(6)	100%	100%
Financial	Net results	(279)	299	(763)	-107%	273%
	Net value in millions of USD	**(930.8)**				

Figure 18. Social cost of the Las Cruces hydroelectric project (source: created by authors).

The most significant underlying factors in the analysis, based on their benefits and costs for society, include:

1) job creation (658.2 MDP or 40 MUSD)
2) a decline in carbon capture and storage capacities derived from a loss in wetlands and mangroves, derived in turn from changes in flooding regimes of the San Pedro River along the watershed's coastal floodplain (5.9 BDP or 360 MUSD)
3) GHG emissions released by the reservoir (1.7 BDP or 103 MUSD)
4) the loss of ES provided by forests that would be flooded by the reservoir (2.7 BDP or 166 MUSD)
5) financial losses due to the imbalance between project costs and revenues from electricity sales (4.6 BDP or 279 MUSD).

The creation of jobs for the five years of project construction represents the only social benefit (658.2 MDP or 40 MUSD). The variability in magnitude of benefits provided to society would change based on the wages paid to the workers, which would depend on the CFE.

The reduction of wetland areas in the lower part of the San Pedro River watershed, as a consequence of flooding regime changes derived from dam construction, would generate a high social cost through the loss of carbon sequestration and storage capacity. Changes were valued based on the reduction in wetland area indicated by the model (2,257 ha), and the potential transformation of a wetland ecosystem to a type of tropical forest, reducing carbon capture and storage functions. The social cost of carbon per ton of CO^2 was also considered.

The creation of the Las Cruces reservoir would imply negative costs to society from the emission of GHGs (mainly carbon and methane) as a result of decomposition of organic material from the flooded forests and terrestrial ecosystems, as well as from vegetation transported by the river to the dam. In the model, the size of the reservoir-affected area (4,588 ha) and the social cost of carbon (78 USD/t/Co_2-eq) must be included alongside the process of decomposition and its resulting emissions (76.5 gCo_2-eq/kWh). The variability of the social cost of reservoir emissions is ample, and it is not only influenced by the social cost of carbon (between 30 USD/t/Co_2-eq and 200 USD/t/Co_2-eq), but also by the emissions quantities (between 40 gCo_2-eq/kWh and 112 gCo_2-eq/kWh). The amount of gas emissions changes according to climate, increasing in tropical reservoirs as indicated by other reservoirs in amounts of up to 2,000 gCo_2-eq/kWh in regions of similar climatic conditions.

The construction of the hydroelectric project entails the destruction of 5,493 ha of forested land and with them the loss of the ES provided by these terrestrial habitats. The social cost of this loss is estimated at 2.7 BDP based on the results published by De Groet et al., (2012), which encompass mainly provision, regulation, and habitat services.

The results of the financial analysis indicate that under the current scenario (electricity selling price, 2017: 542 MXN/MWh), the Las Cruces hydroelectric project is not financially profitable since total generated revenue (16.6 years) would add up to a total of 6.75 BDP, which is less than the costs projected by the CFE (10.49 BDP), creating a social cost of 4.6 BDP or 279 MUSD. If a construction cost overrun of 70% is added to the initially predicted amount, and the selling price is maintained, the social cost would climb to 11 BDP; in this case, the selling price would have to be raised to 1,546 MXN/MWh to reach a profitability threshold. This is a very unlikely price, as the electricity market would not permit higher selling prices unless they are strongly subsidized by the Mexican government (regardless of the mechanism), which represents a negative cost to society.

Only under the best conditions, where there are no cost overruns and a higher price is applied (electricity selling price, 2016: 935 MXN/MWh), could the project's total revenue reach 11.6 BDP, in which case net revenue for Las Cruces would exceed 1.1 BDP.

It is important to consider the production potential of the hydroelectric project in the analysis, which in the model was based on a constant future production potential that may well not occur for two reasons: On the one hand, the developed model has a timespan of 25 years throughout which the dam could lose approximately 10% of its capacity due to sediment retention. On the other hand, possible changes in precipitation and water availability are not being considered. Given the will of the government to reduce subsidies, the Las Cruces hydroelectric project does not appear to be profitable.

Finally, there is currently no evidence that the electricity produced would affect the local market regarding prices and access to electric energy in Nayarit. The goal of the Mexican electric sector is to reduce electricity prices, which without additional subsidies, does not seem favorable for the Las Cruces project. Subsidies in this case are regarded as a negative impact on Mexican society since these represent an additional public expense usually covered by national debt.

3.2 Sensitivity Analysis

The sensitivity analysis is shown in Table 11 and Figure 18. It indicates how the results change according to the variability of key parameters included in the model. The following section discusses the parameters and associated results that demonstrated the greatest variability.

In the case of the project's job creation capacity and the magnitude of benefits that this could generate for society, it clearly depends on the wages paid to the workers; in this case, the most significant differences are seen between the living wage (4,955 MXN/month) vs. the minimum wage in Mexico (1,680 MXN/month), and the number of jobs created (14,000 FTE vs. 28,000 FTE if 5,000 indirect jobs are created).

The change in ES provided by the watershed's terrestrial ecosystems that would be modified and destroyed by the construction of the project varies depending on the values used in each estimate, which have a range between 13,128 MXN/ha/year (minimum value) and 232,820 MXN/ha/year (maximum value) and depend on the authors of each of the referenced studies.

The parameter referring to the social cost of carbon is important to keep in mind since the average (1,280 MXN/tCO_2e), minimum (640 MXN/tCO_2e), and maximum values (3,282 MXN/tCO_2e) used as references vary greatly depending on the source, and in turn affect several of the valued ES, as well as values in GHG emissions released by the reservoir, and the decline in carbon capture and storage from wetland loss. The valuation of the social cost of GHG emissions released by the reservoir vary depending on the amount of organic material undergoing decomposition processes and their rate of deterioration; this data differs from one author to another and on the conditions in which measures were taken (e.g., latitude, climate, etc.). The applied ranges for carbon are from 386 mgC/m^2/day to 660 mgC/m^2/day, and from

24 mgC/m^2/day to 112 mgC/m^2/day for methane. The social cost of carbon is one of the most significant parameters contributing to the dam's impacts. Under average conditions it generates the largest negative impact, and using higher estimates it becomes the second biggest factor.

In the case of fisheries, the differences observed respond principally to the methodologies employed by the authors as references, and hence the estimates of the value that the mangroves create for breeding grounds. The variability of this parameter spans from zero, where it was assumed that the decline in wetlands from flood regime changes would not have any effect on fishery resource productivity, to 615,375 MXN/ha/year. The 886 MXN/ha/year taken as an average value for valuating fisheries was calculated based on the productivity value of local fisheries in the wetland area (Akker et al., 2012), while Pronatura Noreste A.C. estimated 615,375 MXN/ha/year from considering the mangrove margins in contact with brackish bodies of water in their calculations. When considering the highest estimates, the fisheries impact becomes the biggest contributor to the impacts of the dam.

The variability of net results specifically respond to two parameters: 1) the estimated cost of the project, which had a range of 10.49 BDP estimated by the CFE and 17.8 BDP if a 70% cost overrun is applied according to analyses in recent publications where the real costs of worldwide hydroelectric dam construction are assessed, and 2) the selling price of electricity, which varies between 542 MXN/MWh (estimate for 2017 following the liberalization of the electric energy market for Mexico) and 935 MXN/MWh (estimate for the second half of 2016). Net financial results remain the third biggest negative impact when considering high estimates, but it becomes a positive value when considering the lowest estimates.

3.3 Benchmarking

The Policies for the National Energy Strategy of Mexico and its international commitments ratified in the Paris Agreement (September 21, 2016) include investments in diversifying their electricity matrix, increasing contributions of renewable energy resources (the fraction of renewable energy sources in the national electricity matrix is currently 15%), achieving thus a reduction in carbon emissions. Although the goal proposed by Mexico is to reduce GHG emissions by 22% below the baseline by 2030, these objectives are not consistent with limiting global warming to 2˚C[10].

The construction of hydroelectric projects is one of the solutions proposed by the Mexican government for reducing the country's emissions, and among those projects is the Las Cruces dam, which could prevent the emission of 304,807 tCO_2eq of annual GHGs emissions according to calculations by the CFE (CFE, 2014). The results of the present study indicate that the reduction in emissions would be, in effect, 51,657 tCO_2eq per year. Figure 19 contains a

[10] http://climateactiontracker.org/countries/mexico.html, 2017.

comparison of GHGs emissions (in gCO_2-eq/kWh) of different energy production sources in Mexico, including the Las Cruces hydroelectric project, and includes the minimum and maximum ranges for emissions that were applied in the model. The Las Cruces hydroelectric project's emissions (503 gCO_2-eq/kWh) exceed those of combined natural gas (428 gCO_2-eq/kWh), and are below emissions generated by the production matrix of electric energy in the country (572 gCO_2-eq/kWh).

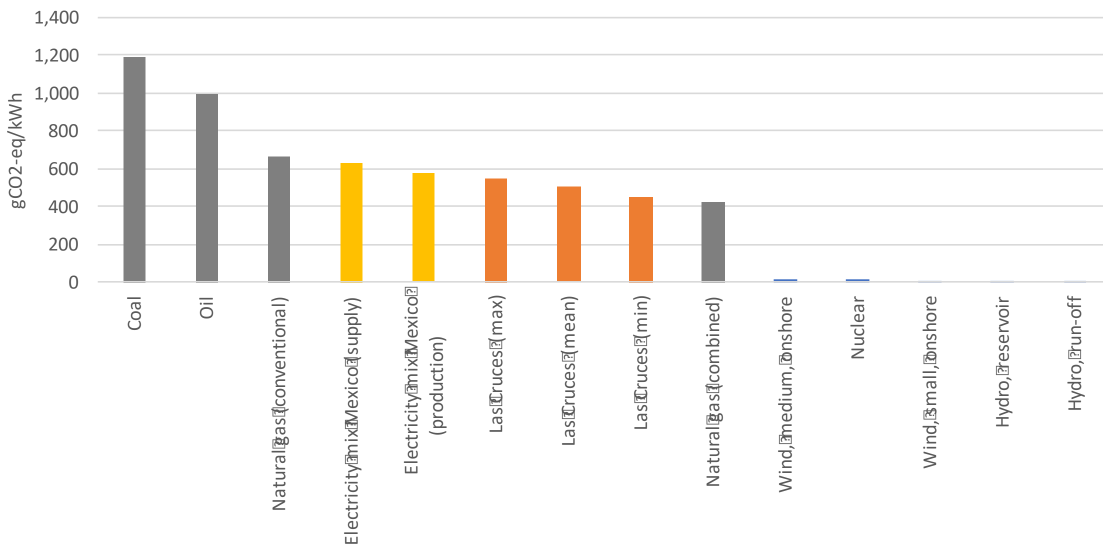

Figure 19. Comparison of GHG emissions by different sources of electricity production in Mexico (source: Ecoinvent database, 2017).

In addition to analyzing the effects of GHGs emissions, a second comparison of the Las Cruces project was made considering all impacts besides GHGs emissions (Figure 20). There is no financial information on job creation for the examples compared to Las Cruces, so these aspects were not included in the analysis. The results of the different sources are expressed in USD per kWh.

The results indicate that the Las Cruces hydroelectric project (average values, 0.06 USD/kWh) produces more externalities than other sources of renewable energy for electricity generation; it is placed below natural gas and the energy production matrix in Mexico (0.17 USD/kWh). Based on this graphic comparison, a shift from nonrenewable energy sources to hydroelectric electricity generation can be considered to be a positive change. However, it is also concluded that the potential impact of the Las Cruces hydroelectric project is much greater than other sources of renewable electricity, to the extent that the Las Cruces project cannot longer be called “renewable”.

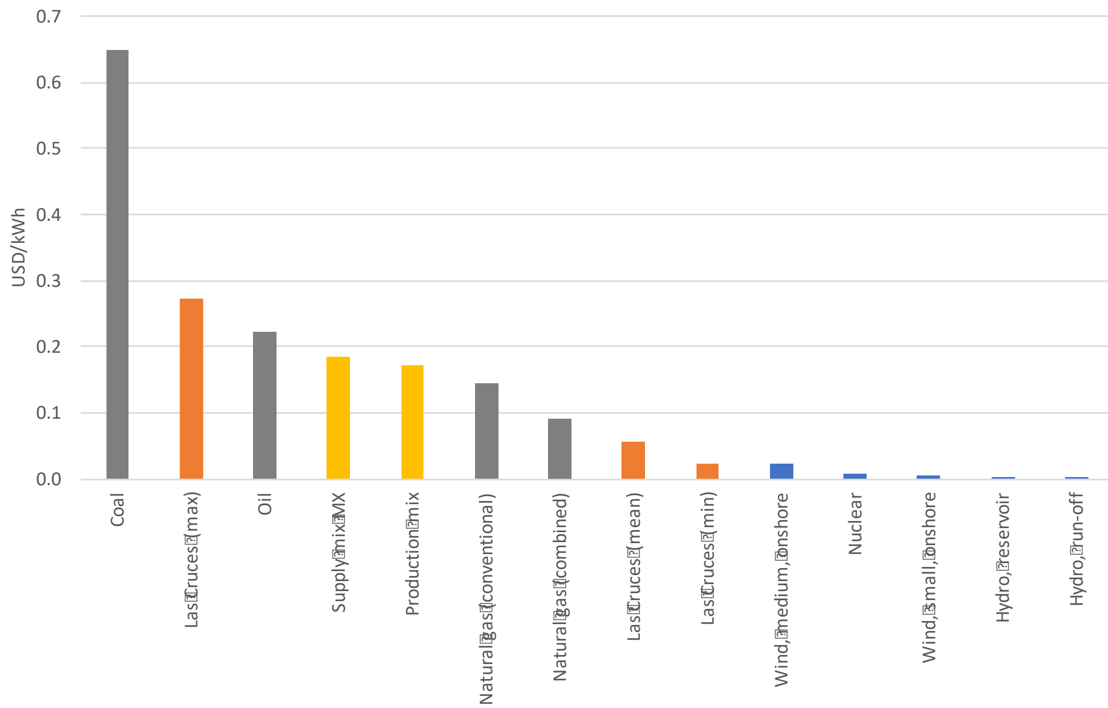

Figure 20. Comparison of externalities created by different sources of electricity production in Mexico (sources: Ecoinvent database, 2017; Valuing Nature internal data, 2017).

4 Conclusions

This study presents an innovative framework for comprehensively evaluating the externalities generated by public infrastructure works like hydroelectric dams, thereby upholding informed decision-making at different levels. The employed methodologies are, today, one of the most comprehensive, and include the latest advances in the field of social and natural capital accountability used by the private sector. The model developed for analyzing the project's impact pathways showed diverse results that include positive and negative externalities.

The cost-benefit analysis of the project indicated a net social cost for Mexican society of 15.3 BDP in a time horizon of 25 years. The effects were analyzed by quantifying the changes caused by the construction of the project on natural and social capital that included direct impacts from construction on local communities (positive and negative), as well as impacts on ES resulting from changes in flooding and sedimentation regimes of the San Pedro River in the lower part of the watershed after the reservoir. The costs (15.9 BDP) are greater than the benefits (652.2 MDP) and are influenced mostly by a decline in carbon capture and storage as a result of the loss of wetlands from changes in flooding regimes, reservoir-induced GHG emissions, and a loss in ecosystem services from the alteration and destruction of land ecosystems, all ultimately a result of project construction (e.g., flooding from the reservoir). The positive impacts include the creation of jobs for constructing the dam but only under the best project conditions, and financial benefits generated by the selling price of electricity at its highest estimate. Notwithstanding, given the present conditions of the electricity market in the country, this scenario is considered to be of low probability.

The scope of the study was developed based on the availability and accessibility of information and public databases. There are other impacts that could have been included in the analysis, therefore implying the potential for improved precision of results, though requiring access to unpublished information or the development of research that could fill in the present gaps in information. The lack of access to information for the development of the study was an obstacle, and the conclusions could change based on new data. The presented results offer a frame of reference for considering and analyzing positive and negative impacts, and do not constitute a definitive vision of the Las Cruces hydroelectric project.

Compared to other sources of renewable electricity generation, the Las Cruces hydroelectric project does not provide the contribution that the Mexican government hopes to reach its goals of GHG emissions reduction. Additionally, a benchmark analysis of externalities produced by different sources of electricity generation in Mexico shows that the Las Cruces hydroelectric project is more comparable with a natural gas thermal power plant than with other types of renewable electricity production.

We hope that the framework and methodology employed in this analysis will contribute significantly to the evaluation of worldwide mega- infrastructure and public investments.

5 Literature Cited

Akker, I., M., Corona, S., Lummis, H., Wong, C., Zabel. 2012. Marismas Nacionales Conservation & Carbon Sequestration, preliminary report. Stanford Students Environmental Consulting, Stanford University. 58pp.

Arthington, A. H., R. L. Welcomme. 1995. in Condition of the World's Aquatic Habitats by N. B., Armantrout, R. J., Wolotira Jr. Science Publishers, Lebanon.

Avakyan, A. B., V. B., Lakovleva. 1998. Lakes Reserves. Res Manag, 3: 45.

Brune, G. 1953. Trap efficiency of reservoirs. Eos Transactions American Geophysical Union, 34-407-418.

CBD. 2015. Wetlands and Ecosystem Services. Wetlands for future, Press Brief. Convention on Biological Diversity International. 10pp.

Chang, S. P., C. G., Wen. 1998. Water Sci Technol, 37: 325.

Cotler≣H.,≣Garrido≣A.,≣Mondragón≣R.≣y≣Díaz≣A.≣2007.≣Delimitación de cuencas≣hidrográficas de México a escala 1:250,000, INEGI/INE/CONAGUA. Documento técnico. México.

Danemann, G.D., G., Cordero, M., Cortés, C., Torrescano, V., Valdéz. Valor Económico de las Pesquerías generadas por el Ecosistema de Manglar en Marismas Nacionales, México. Programa de Conservación Marina y Pesca Sustentable, Pronatura Noroeste A. C.

Deemer, B.R., et al. 2016. Greenhouse Gas emission from reservoir water surfaces: A new Global Synthesis. BioScience, 66:11.

EPA. 2017. The social cost of carbon: estimating the benefits of reducing Green House Emissions.
Gehrke, P. C., D. M., Gilligan, M., Barwick. 2002. River Res Appl, 18:265.

Garrido, et al., 2009. Zonas funcionales de las cuencas hidrográficas de México, escala 1:250,000. México: INE, SEMARNAT.

Gillett, R. M., P. V. Tobias. 2002. Am. J. Hum. Biol. 14, 50.

Gornitz. 2000. in Sea Level Rise: History and Consequences by Douglas et al. Academic Press, San Diego, CA. 97–119pp.

Hergoualc'h, K., L.V., Verchot. 2011. Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: a review. Global Biochemical cycles, 25:GB2001.

Humborg, C., V. Ittekkot, A. Cociasu, B. VonBodungen. 1997. Nature 386:385. 9. C.

Indrabudi, H., A. De Gier, L. O., Fresco. 1998. Land Degrad Dev, 9: 311.
International renewable energy Agency - IRENA. 2012. Technologies cost analysis hydropower.

Jansson, R., C. Nilsson, B. Reno¨fa¨lt. 2000. Ecology 81: 899.

Kolka, R. K., D., Murdiyarso, J.B., Kauffman, R. A., Birdsey. 2016. Tropical wetlands, climate, and land use change: adaptation and mitigation opportunities. Wetlands Ecol Manage, 24:107-112.

Lemly, A. D., R. T., Kingsford, J. R., Thompson. 2000. Environ Manag, 25: 485.
McCully, P. 1996. Silenced Rivers. Zed Books, London.

Moore, F. C., D. B., Diaz. 2015. Temperature impacts on economic growth warrant stringent mitigation policy. Nature climate change, 5:127-131.

Nilsson, K. Berggren. 2000. Bioscience, 50: 783.

Nilsson et al. 2005. Large River Systems Fragmentation and Flow Regulation of the World's. Science 308: 405.

Nordhaus, W. D. 2016. Revisiting the social cost of carbon. PNAS, 114:7, 1518-1523.

Parsaie et al. 2017. Investigation of trap efficiency of retention dams. Water Science and Technology: Water Supply.

Penczak, T., A., Kruk. 2000. Ecol Freshw Fish, 9: 109.

Poff et al. 1997. Bioscience, 47:769.

Prowse et al. 2002. Water Int, 27:58.

Rosa, L. P., M. A., dos Santos, B., Matvienko, E. O., dos Santos, E., Sikar. 2004. Clim Change, 66: 9.

Schuyt, K., L., Brander. 2004. The Economic Values of the World's Wetlands. World Wildlife Found, The Netherlands. 30pp.

Sovacool, B. K., D., Nugent, A., Gilbert. 2014. Construction Cost Overruns and Electricity Infrastructure: An unavoidable risk?. The Electricity Journal, 27:4.

St. Louis, V. L., C. A., Kelly, E., Duchemin, J. W. M., Rudd, D. M., Rosenberg. 2000. Bioscience 50, 766.

Tockner, K., J. A., Stanford. 2002. Environ Conserv, 29:308.

Voora, V., S. Barg. 2008. Pimachiowin Aki World Heritage Project Area Ecosystem Services Valuation Assessment. International Institute for Sustainable Development / IISD. 56pp.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B. 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8>.

World Commission on Dams. 2000. Dams and development: A new framework for decision-making. Earthscan Publishing, London.

6 Annexes

6.1 Environmental Impact Caused by the Construction of the Reservoir and the Operation of the Hydroelectric Generation System

The following tables show the environmental impacts identified by the CFE that were linked to the project, and which were published in the EIS document (CFE, 2014). The first table corresponds to the environmental impacts generated from the construction of the reservoir, and the second table indicates the impacts generated by the operation of the hydroelectric system.

Impacts	Impact Category	Mitigation Capacity (M)	Compensation (C)	Relation with preexisting change drivers	Geographic Reach (UAR)	Certainty of Impact Magnitude
Loss of vegetation land cover	1	×	C	✓	1	⇧
Effects on NOM species of terrestrial flora and fauna	2	×	C	✓	1	⇔
Fragmentation of land habitats	1	×	C	✓	1	⇔
Alteration of biological corridors	1	×	C	✓	1	⇔
Modification of productive activities in reservoir area	1	×	C	✓	1–4	↓
Landscape alteration	1	×	C	×	1	↓
Flooding of San Blasito town	1	×	C	×	1	⇧
Flooding of cultural sites and effects on ceremonies	1	×	C	×	1	⇧
Demographic growth in nearby towns	1	M	×	×	1, 2, 3	⇧
Change from lotic to stratified lentic regime	1	×	×	×	1	⇧
Substitution of aquatic ecosystems	2	×	C	×	1	⇔
Effects on NOM species of aquatic flora and fauna	2	×	C	×	1–4	⇔
Increase in water evaporation from reservoir area	2	×	×	×	1, 2	⇧
Interruption of aquatic species migration	2	M	×	×	1–4	⇧
Retention of organic material, nutrients, and sediment	1	×	C	×	1–4	⇧
Generation of GHGs from anaerobic decomposition	1	×	×	×	1	⇧
Alteration of geomorphologic processes downstream of the dam wall	1	×	×	✓	3–4	↓
Effects on material extraction activities	1	×	×	✓	1–3	↓
Formation of deltas and organic/ inorganic material deposits	1	×	×	×	1	↓
Induced local seismicity	1	×	×	×	1, 3	⇔

Impacts from operation of hydroelectric generation system	Impact Category	Mitigation Capacity (M)	Compensation (C)	Relation with preexisting change drivers	Geographic reach (UAR)	Certainty of Impact Magnitude
Variation of daily flow regime	1	M	×	×	2–4	⇧
Variation of seasonal regime	1	M	×	✓	2–4	⇧
Decline in magnitude of flood surges in coastal plain during rainy season	2	M	×	×	2–4	⬄
Changes in land use of floodplains	2	×	×	✓	3–4	⇧
Modification of productive activities of coastal floodplains	2	×	×	×	3–4	⇧
Increase in water availability during dry season	2	×	×	✓	2–4	⬄
Variation in inter-annual regime	1	M	×	×	2–4	⇧
Modification of nutrient and sediment transportation in San Pedro River	1	×	C	×	2–4	↓
River flow incision and straightening due to increase in flow velocity and erosive processes	2	×	×	✓	2–4	↓
Modification of river pools and gravel/pebble beds	2	×	×	✓	2–3	↓
Modification of morphogenetic processes in floodplains and wetlands	1	×	×	✓	3–4	↓
Modification of nutrient and sediment transport to lagoons	2	×	C	✓	2–4	↓

6.2 Results with Discount Rate Included

The following table and figure show an analysis of the social cost of the Las Cruces hydroelectric project with a discount rate of 3.9%.

		Average estimates	Low estimates	High estimates	Low estimates (relative change to mean)	High estimates (relative change to mean)
		MUSD	MUSD	MUSD	%	%
Social impacts	Jobs	591.3	1,399.0	253.5	226%	43%
	Sacred sites	(55.8)	(34.9)	(174.3)	63%	313%
	Displaced population	(33.2)	(33.1)	(33.7)	100%	102%
Impact of project	Land covered by reservoir	(1,508.6)	(760.0)	(1,900.0)	50%	126%
	Reservoir's emissions	(955.1)	(198.6)	(3,574.0)	21%	374%
	Dam's construction carbon footprint	(145.7)	(56.0)	(373.5)	38%	256%
Flooding regime	Water quality	(14.3)	(11.3)	(17.2)	79%	121%
	Biodiversity/habitat	(14.1)	(6.3)	(21.8)	45%	155%
	Carbon storage and sequestration	(3,341.3)	(1,285.1)	(8,567.6)	38%	256%
	Fisheries	(22.7)	–	(15,729.4)	–	69444%
	Agriculture	(109.3)	(33.1)	(182.2)	33%	167%
Sediment regime	Water quality	(0.5)	(11.3)	(17.2)	79%	121%
	Biodiversity/habitat	(0.4)	(6.3)	(21.8)	45%	155%
	Carbon storage and sequestration	(142.1)	(1,285.1)	(8,567.6)	38%	256%
	Fisheries	(0.7)	–	(15,729.4)	–	69444%
	Agriculture	(33.1)	(33.1)	(182.2)	33%	167%
	Extreme events protection	(50.2)	(50.2)	(50.2)	100%	100%
Financial	Net results	(6,290.2)	(3,704.0)	(13,182.)	59%	210%
	Net value in millions of USD	(12,125.9)				