Chapter 3
Galapagos' Water Management Evaluation Under a Changing Climate and the Current COVID-19 Pandemic

Cristina Mateus and Diego Quiroga

Abstract This chapter analyzes the Galapagos as a socio-ecosystem and addresses the interactions of social and environmental systems amidst important transformations that the Islands are experiencing. We look at two of the most important threats to the Galapagos socio-ecosystem, the current COVID-19 pandemic and the possible effects of climate change as they affect and are affected by the water security of the islands. Water availability in both the urban and the rural areas is examined as a key factor that affects the resilience of the people who reside in the islands and their capacity to adapt and withstand dramatic and often catastrophic changes. We also consider the way different institutions and strategies have operated, usually in a top-down fashion in generating projects to increase the capacity of the Islands to adapt to climate change, and we examine the effectiveness of some of these often expensive projects. Thus, the main goal of this analysis is to understand how these critical threats harm Galapagos local community and economy, both in the short and long term by taking into account the success and failures of past projects, and then explore possible actions and plans to address them.

Keywords Socio-ecosystem · Climate variability · Covid-19 · Water availability · Water security

3.1 Introduction

Galapagos' ecotourism economy which is increasingly dependent on the global socioecological dynamics is starting to be impacted by climate variability, water security, and the current COVID-19 pandemic. Social capital which is based on the trust and transparency of the local institutions and the existing social networks is an

C. Mateus (✉) · D. Quiroga
Universidad San Francisco de Quito, Instituto Biósfera, Quito, Ecuador

Galapagos Science Center, Galapagos, Ecuador
e-mail: mcmateus@usfq.edu.ec; dquiroga@usfq.edu.ec

A. L. Thompson et al. (eds.), *Water, Food and Human Health in the Galapagos, Ecuador*, Social and Ecological Interactions in the Galapagos Islands,
https://doi.org/10.1007/978-3-030-92411-9_3

important part of social resilience. In this analysis we will look at the way in which social resilience relates to the capacity of Galapagos' society to respond to new threats such as the COVID-19 pandemic and climate change particularly as they relate to water availability.

The strong relationship that exists between the current health crisis and the climate crisis needs to be explored and evaluated more in depth. Since COVID-19 health and economic impacts around the world became visible immediately, most countries' political agendas prioritize the preservation of human lives. However, climate change's most pressing issues have not been given equal importance as COVID-19 even though it has become clear that addressing climate should also be a priority in order to preserve human lives, livelihoods, and the economy. Both COVID-19 and the early effects of climate change have become an important challenge to the people living in Galapagos as they have interrupted the flow of tourist on which the local communities depend on a large extend for their income and economic survival.

Climate change in Galapagos threatens to exacerbate stresses on both the natural and built environments due to increases in the frequency and intensity of EL Niño Southern Oscillation (ENSO) floods, sea level rise, soaring sea surface temperatures (SST), heat waves (d'Ozouville et al. 2010; Larrea and Di Carlo 2011), and decreases in ocean pH and intensity of upwelling (Sachs and Ladd 2010). Climate change may also have the opposite effect of decreasing SST and causing prolonged periods of drought. These important changes can affect both food security and the survival of some species whose numbers are already very low. The presence of these species is important not only due to their intrinsic and scientific value but also for the flow of tourists to the islands.

The increasing number of permanent residents and tourists (DPNG 2017; INEC 2015) exacerbates the need to develop alternatives to support the increased demand for water and agricultural products. Higher demand for food resulted in more agricultural products being imported from the mainland to meet those demands. This increased dependence on mainland products was related to environmental and social factors such as the lack of water, poor soils in some areas, and the cost of labor. For many of the locals, it was better, until COVID-19, to work on tourism, commerce, transportation, and the public sector than to work in the field in the highlands. This lack of access to fresh food and increased processed food supply from the mainland resulted in Galapagos having one of the highest rates of obesity in Ecuador. Now, in the midst of the COVID-19 pandemic, which has resulted in the collapse of the tourism economy, there is an increased dependence of agricultural products coming from the highlands. This requires proactive strategies that are more self-sufficient, making the islands even more vulnerable to climate change.

Climate change may also exacerbate the tension of increased human presence on the island. While additional population growth will add to the amount of effluents produced on the islands (GAD Santa Cruz 2007), an increase in extreme events such as intense storms or floods (Larrea and Di Carlo 2011) will also flush more of these effluents into the ocean and groundwater and surface water systems, thus deteriorating the quality of the water. On the other hand, prolonged droughts during La Niña can affect the availability of freshwater for human consumption and food security as there is not enough water in the highlands where agriculture is centered. Thus, this lack of freshwater or water of good quality most likely will have a negative impact in the islands' agricultural capabilities, especially in Santa Cruz and Isabela where there are already issues with freshwater supply to satisfy the high demand that accompanies the expansion of the tourism industry. Although the number of tourists arriving to the Galapagos dramatically decreased since COVID-19, most likely, the number will recover in the short term. The challenge is whether under the current circumstances of increased fluctuations and unpredictability of water availability, the islands' socio-ecosystems can maintain their resilience and their capacity to adapt to some of the threats that will result from climate change.

Being tourism the main source of income in Galapagos, diseases that affect human health could also have a major impact on the economy. In other areas of the world, it has been reported (Ahmadi et al. 2020) that the most important variables affecting the COVID-19 outbreak rate are population density. In the case of the Galapagos, there has been a significant increase in density in populated areas during the last five decades which has resulted in greater vulnerability to the effects of infectious diseases. Besides density, Galapagos has become much more interconnected to the mainland as the number of flights and cargo boats arriving to the islands increased exponentially during the last decades. The dual effects of increases in density and connectivity resulted in the arrival and spread of diseases such as dengue fever and other mosquito-transmitted diseases as well as influenza and more recently COVID-19.

Additionally, some of the possible effects of climate change such as increase in precipitation and warmer weather are expected to exacerbate many kinds of diseases, especially those that have insects as vectors. Recent studies suggested that temperature variation and humidity may be important factors affecting COVID-19 transmission, which decreased with temperature increasing (Wang et al. 2020), and mortality (Ma et al. 2020). People living in areas with higher exposure to warmer temperatures, droughts, food shortages, loss of clean water, access to healthcare, and/or disease exposure are far less able to fight off the COVID-19 pandemic (Wu et al. 2020). The lack of good medical facilities and specialized physicians, as well as exposure to climate extremes and thus lack freshwater supply, makes the Galapagos a vulnerable area for these kinds of pandemics.

Rethinking and understanding the importance of the relationship between local community, NGOs, technical specialists, and policy to address the current climate and health crisis is crucial. Through a structured multi-stakeholder approach combining the contributions and recommendations and perspectives of technical specialists, local community, NGOs, and governmental institutions, we evaluate the effectiveness of government plans to address climate change issues on the water and food sectors and define a research path and adaptive strategies for the local communities facing the current climate and health crisis. Thus, the analysis is broken down into two sections. First section identifies water and climate needs and priorities described by all stakeholders taking into account funds that were allocated to address water management and climate change issues, the efficacy of implementation and results, and the progress of such plans beyond government periods. Therefore, recommendations are based on failure and success of proposed actions to address those needs. Second section of the analysis consists on evaluating results from the previous section under two different scenarios: (1) considering only climate change crisis, and (2) considering both climate change and COVID-19 pandemic crisis. Finally, we discuss possible alternatives to address these issues and increase Galapagos resilience to catastrophic changes.

3.2 Methods

3.2.1 Study Area

In general, inhabited islands in the Galapagos suffer of insufficient water supply of adequate quality to meet the increased demand for domestic use and irrigation. Brackish water can be found on all the islands, yet only San Cristobal has an adequate freshwater supply due to its permanent surface freshwater bodies (Maria Reyes et al. 2017). There is a series of freshwater aquifers in San Cristobal island leading to multiple water spring alignments and perennial streams (d'Ozouville 2007; Violette et al. 2014). On the other hand, both Santa Cruz and Isabela islands lack of freshwater supplies and rely on municipal desalination plants that use reverse osmosis to treat brackish water (J. Liu and d'Ozouville 2013). However, either desalination plants functionality is not reliable such as is the case in Santa Cruz or there is not enough storage capacity for treated water such as is the case in Isabela. Water sources in Santa Cruz and Isabela are characterized by basal aquifers at lower elevations (brackish) and deep boreholes at higher elevations where water is fresher (Violette et al. 2014). Brackish water at lower elevation in Santa Cruz island results from both seawater intrusion and overexploitation, and it is contaminated with both organic (J. Liu and d'Ozouville 2013) and inorganic (López and Rueda 2010) matter. At higher elevations, water is fresher since it is extracted from deep boreholes (Reyes et al. 2016; Violette et al. 2014). In general, there is very little supply of freshwater for irrigation purposes for the farmers in the islands (d'Ozouville 2007), an issue exacerbated with more frequent droughts and floods as a result of changes in precipitation patterns and warmer temperatures (Izurieta et al. 2018).

In 2016, the *Ministerio de Agricultura, Ganadería, Acuacultura y Pesca* (MAGAP) invested USD 1,172,728 (MAGAP 2016) for the construction of 130 small reservoirs distributed as follows: 53 in San Cristóbal, 46 in Santa Cruz, 26 in Isabela, and 5 in Floreana (MAGAP 2019). Nevertheless, many of these small reservoirs are not fully functional or do not have access to enough water supply to meet agricultural demands. This happens especially during strong periods of drought as the one that occurred in 2015–2016 when cattle had to be sacrificed and many farmers lost their crops.

In San Cristóbal island, the surface water generally meets domestic and agricultural water requirements (Grube et al. 2020). The 17 main springs present in the island meet both domestic and irrigation demands when sufficient and adequate infrastructure is available (CISPDR 2015). During prolonged dry seasons however, farmers that don't have access to perennial streams rely on rainwater collection and municipal tank trucks (CISPDR 2015). Increases in irrigation water deficits are expected by 2035, and thus exploitations of alternative water sources and water-saving irrigation techniques (i.e., sprinkling, dripping, micro sprinkling, hydroponic, etc.) have been proposed (CISPDR 2015). There are two main water sources located in the highlands to supply water for urban areas: (1) La Toma with El Progreso Drinking Water Plant and (2) Cerro Gato with Las Palmeras Drinking Water Plant. While San Cristobal has an adequate freshwater supply due to its permanent surface freshwater bodies (Maria Reyes et al. 2017), limited water supply from the municipal drinking water forces households to store water in roof tanks or cisterns (Grube et al. 2020). Furthermore, while water treatment plants are able to produce water that meets drinking water standards, contamination of this water seems to be happening through the distribution system and household storage (Grube et al. 2020).

Santa Cruz island has eight water sources for irrigation and three main sources of municipal water for Puerto Ayora (Grieta la Camiseta), Bellavista (Pozo Profundo), and Santa Rosa (Vertiente Santa Rosa) (CISPDR 2015). However, water is scarce and has a high salinity concentration, making it unsuitable for drinking and long-term use in agriculture as it causes alterations of soil properties (Mateus et al. 2019). While MAGAP reservoirs could help irrigation plans and infrastructure for a few areas in the highlands, there has not been sufficient rain to supply the reservoirs. Additionally, there are a few private operations extracting water from crevices that have no regulation or monitoring and thus the amount extracted is unknown (Reyes et al. 2015). In many of these places, groundwater is contaminated due to the proximity of the basal aquifer to dense urban settlements, the lack of effective wastewater treatment plants, and, in some cases, sea water intrusion due to overexploitation of the aquifer (López and Rueda 2010; Violette et al. 2014; Mateus et al. 2019).

Isabela island's natural pools and crevices contain freshwater from rainwater; however, a few meters deep, the water is brackish and salty (Violette et al. 2014). There is no water distribution system for the agricultural and livestock sectors, which completely depend on MAGAP tankers and couple of other distributors (CISPDR 2015). The islands have five water sources for irrigation, and three main sources for municipal water for urban areas come from La Poza San Vicente located in El Chapin region. From here water goes through a desalinization plant and is stored in tanks before it is distributed to the 94.6% of households that have access to the municipal piped water network. As mentioned before, the current issue is that there is not enough space in the tanks to store water treated by this desalinization plant, and thus this treated water only lasts the first couple of hours from distribution; after that, the water being distributed is brackish.

3.2.2 Study Approach

The analysis is divided into two sections as described below.

3.2.2.1 Multi-stakeholder Approach to Identify Proposed Actions to Address Water Needs and Priorities Under Climate Change

This section replicates the methodology presented by Mateus et al. (2020) which consists in a structured bottom-up and top-down multi-stakeholder approach to classify water needs and priorities identified by technical specialists, local community, and NGOs (bottom-up) and evaluate the effectiveness of the science-government-driven plans (top-down). The methodology entails on five steps briefly described below (please refer to Mateus et al. (2020) for more details).

The approach starts by defining the problem or the need described by users (technical specialist, local community, and NGOs), with input of decision-makers but driven by users and stakeholders (bottom-up). This was done throughout an extensive literature review between 2010 and 2020 to better understand the technical specialists' assessment of the Galapagos' hydroclimatic conditions, freshwater sources, and water management systems for human use (potable and irrigation) in which gaps between climate change and research needs were identified (Step 1). Second, through collaborative workshops conducted on May 21, May 23, and June 13, 2018, in San Cristobal, Santa Cruz, and Isabela, respectively, the local community's, NGOs', and governmental institutions' priorities were identified (Step 2). Workshop participants included stakeholders currently involved in Galapagos' water issues, who would contribute significantly and stay engaged throughout the design and implementation of the water strategy selected. The next step identifies government plans and funding based upon the Development and Zoning Planning, known as "Plan de Desarrollo y Ordenamiento Territorial" (PDOT) which are created by the National Secretary of Planning (SENPLADES 2013) for each island (Step 3). Proposed and executed plans were then evaluated, and reasons for failure and success of such plans are identified (Step 4). Finally, plans and alternative actions for water availability, security, and resiliency under a changing climate were proposed (Step 5).

3.2.2.2 Proposed Action Evaluation Under Two Different Scenarios

Results from Sect. 3.2.2.1 will be evaluated looking at two different scenarios considering the two most important threats Galapagos socio-ecosystem is currently facing, the current COVID-19 pandemic and the possible effects of climate change. The first scenario looks at plans and alternatives proposed taking into account climate change as the only threat. The second scenario evaluates plans and alternatives considering both climate change and COVID-19 pandemic as main threats. This analysis will be made taking into account the fact that COVID-19 crisis could mark a turning point in progress on climate change since the current global pandemic has resulted in significant decreases of greenhouse gas (GHG) emissions. However, emissions will rebound once mobility restrictions are lifted and economies recover. Additionally, as the COVID-19 spreads, it is increasingly clear that public health depends on secure water resources for all, and the people with the least access to essential services like water will feel the most dramatic effects of the pandemic (Otto et al. 2020), such as is the case in the Galapagos.

3.3 Results

3.3.1 Executed Projects and Plans Addressing Climate Change and Water Management Issues in the Galapagos Islands

Approximately USD 138 million was invested in the Galapagos Islands in projects related to water management and climate between 2012 and 2019 (Table 3.1). Most of these projects and government plans focused on addressing climate change impacts and water availability needs in Santa Cruz, San Cristobal, and Isabela islands. While 38% of this funding was invested for community, research, and infrastructure projects in all three islands, the majority of the funding went to projects in Santa Cruz (51%), and the rest of the money (11%) was invested in projects for San Cristobal and Isabela. More information about funding and projects under each initiative with details of project execution and development can be found in the Appendix section (Tables A1, A2 and A3).

Table 3.1 Government funds given to projects that were executed between 2012 and 2019 to address climate and water needs in Santa Cruz, San Cristobal, and Isabela islands

	USD ($)	Percentage
All three islands	**$ 52,552,199**	**38%**
Community	$ 45,810,777	87.2%
Research	$ 49,550	0.1%
Infrastructure	$ 6,691,873	12.7%
Santa Cruz	**$ 71,127,519**	**51%**
Policy	$ 265,184	0.4%
Infrastructure	$ 70,827,335	99.5%
Community	$ 35,000	0.1%
San Cristobal and Isabela	**$ 14,914,637**	**11%**
Infrastructure	$ 6,876,057	46.1%
Community	$ 8,038,080	53.89%
Policy (only for San Cristobal)	$ 500	0.01%
Total invested in water projects	**$ 138,594,356**	**100%**

Between 2013 and 2019, approximately USD 45,8 million was invested in all islands in community projects which includes awareness and trainings to improve conservations of natural resources and sustainable development. Between 2015 and 2017, approximately USD 6.9 million was invested in infrastructure maintenance due to El Niño event and strong precipitation events (mostly road network) as well as construction of sustainable and safe infrastructure in touristic areas. In 2015, the Galapagos Government Council, or CGREG for its initials in Spanish, allocated USD 49,550 in hydrogeological research projects in order to understand and find water sources.

It is important to mention that approximately USD 179,819,308 has been proposed for the "Galápagos compatible con el clima" project in which the responsible agencies are the Development Bank of Latin America (CAF), World Wildlife Foundation (WWF), Food and Agricultural Organization (FAO), CGREG, and Galapagos National Park (PNG). However, neither their plans nor funding is being considered in this analysis.

3.3.2 Agreements Among All Three Groups of Stakeholders

Government plans for Santa Cruz island seem to address the needs and priorities of technical specialists, local community, and NGOs only in areas related with research and community (Fig. 3.1a). All three groups of stakeholders agreed that it is important to improve hydrological data to better understand the water budget and watershed characteristics (d'Ozouville 2008; d'Ozouville et al. 2008; Gonzales Iñiguez 2013; Percy et al. 2016; Violette et al. 2014). This will help water managers in their decision-making process and developing an integrated water resources management plan that considers climate variability and future water scarcity along with the necessary infrastructure that will help adapt and mitigate to new conditions. While plans to address this were proposed by the government (Table A1), only a little amount (USD 49,555) was invested for all three islands to meet this need. Approximately USD 35,000 was invested in 2019 by the government (Table A2) for Santa Cruz (CGREG 2016, 2019; GAD San Cristobal 2017; GAD Santa Cruz 2012) in environmental education campaigns (Responsible: Direccion de Gestión Ambiental). Implementation programs for awareness about water use and conservation of natural resources were proposed during the workshops by stakeholders which agreed with the technical specialists that find this a priority and propose collaborative commitment to understand the consequences of a changing climate and the importance of considering global warming in decision-making processes (d'Ozouville et al. 2010).

In San Cristobal and Isabela islands, there was a general consensus among all parties of the need to create and implement a collaborative management plan to adapt to climate change (d'Ozouville et al. 2010) and seek sustainable development in urban and rural (Fig. 3.1b,c). For this, the government allocated approximately

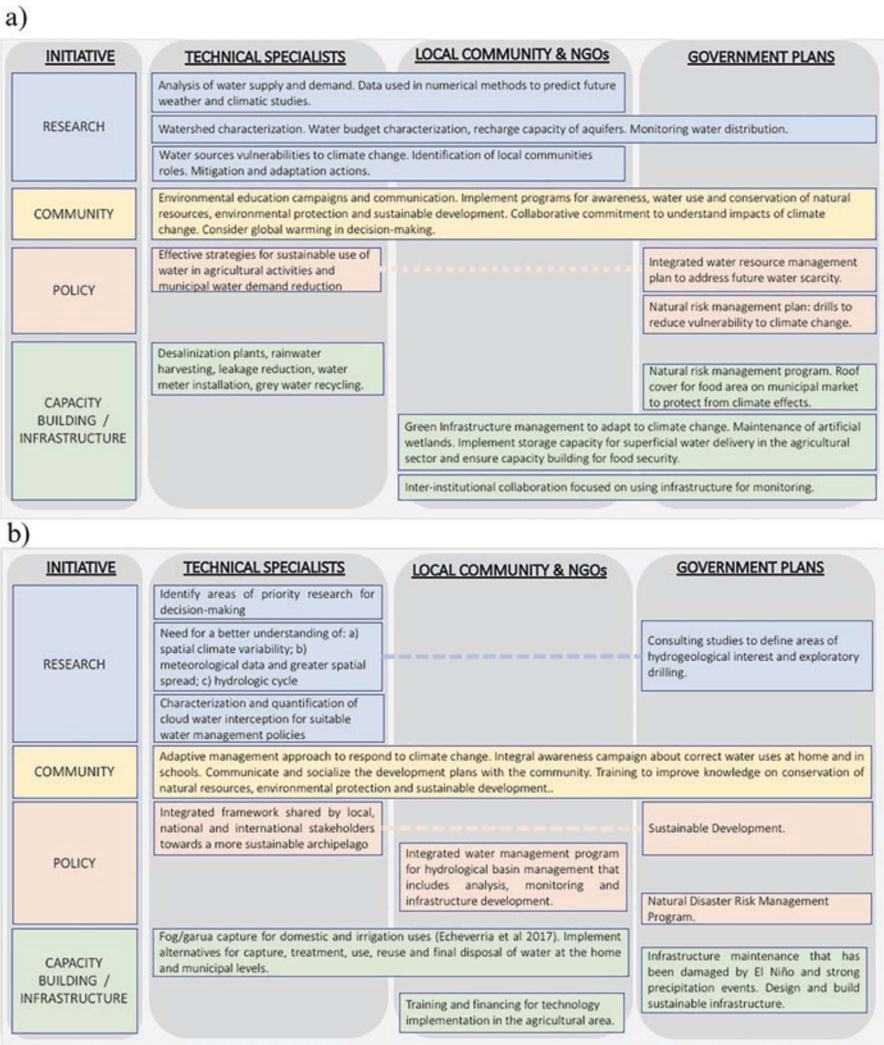

Fig. 3.1 Priorities and concerns identified by technical specialists (Step 1), local community and NGOs (Step 2), and proposed or implemented government plans that address them (Step 3) for (**a**) Santa Cruz Island, (**b**) San Cristobal Island, and (**c**) Isabela Island

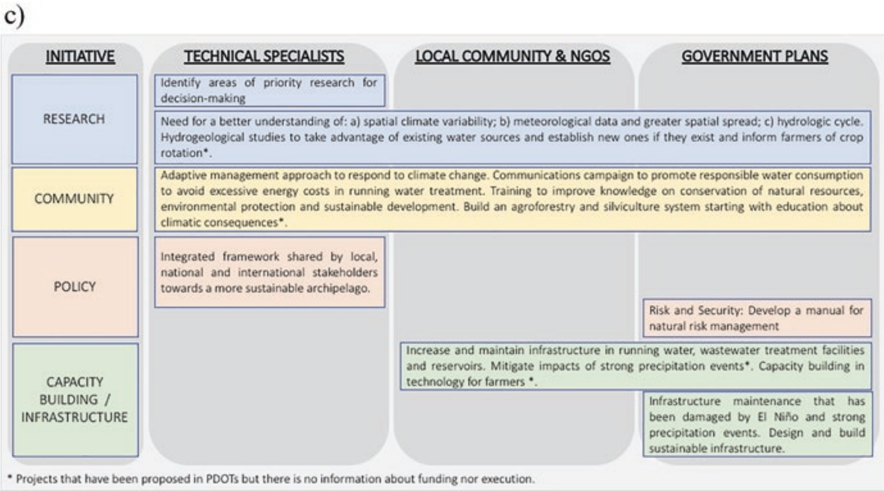

Fig. 3.1 (continued)

USD $ 8 million between 2017 and 2018 (Table A3). Additionally, the technical specialists identified the need for a better understanding of spatial climate variability and access to meteorological data with a greater spatial spread throughout islands (Trueman and d'Ozouville 2010) as well as a better understanding of the hydrologic cycle for Galapagos (Adelinet et al. 2008). This need to improve hydrogeological studies to take advantage of existing water sources and establish new ones (if they exist) was also a priority expressed by stakeholders during the workshop in Isabela (Fig. 3.1c) but not in San Cristobal (Fig. 3.1b). In response to this, the government proposed to develop hydrogeological studies and inform farmers of crop rotation in Isabela island, but the project was never executed. Nevertheless, the government did allocate USD 49,550 (Table A1) for consulting studies to define areas of hydrogeological interest and exploratory drilling in all three islands.

3.3.3 What Has Been Done

In Santa Cruz, approximately USD 71 million were allocated (Table 3.1) for projects addressing climate change and water needs. The majority of the funding (99%) was allocated in infrastructure projects and the rest distributed between policy, community, and capacity building projects as follows:

- Infrastructure: Approximately USD 70 million was proposed (Table A2) to improve infrastructure to adapt to climate change (Fig. 3.1a). Most of the funding was invested on implementing storage capacity for superficial water delivery to the agricultural sector. For example, approximately USD 20 million was invested in Bellavista for the construction of a reservoir, an integral sewage, and potable water system. This project was managed by the Public Works Management, known as DOOPP (Dirección de Obras Públicas), during 2013 to 2016. Approximately, USD 50 million dollars was invested for the same purposes in Puerto Ayora and El Mirador (new urban development near Puerto Ayora) during the same time period. While in June of 2016, it was announced that Santa Cruz will finally have a potable water system (La Hora 2016), by 2019, Santa Cruz still does not have access to potable water, and people still use bottled water to cook, wash food, and for personal hygiene (El Comercio 2019).

- Policy: An integrated water resource management plan was proposed in 2012 by the GAD of Santa Cruz (GAD Santa Cruz 2012) to which USD 228,184 were invested. This addresses technical specialist's suggestions to develop effective strategies for the sustainable use of water in agricultural activities (Izurieta et al. 2018) and a sustainable solution for mitigating the impact on water supply due to a growing demand with the installation of water meters (María Reyes et al. 2019).
- Policy: While approximately USD 177,000 was proposed for Santa Cruz Natural Risk Management Program between 2014 and 2015, only USD 37,000 was invested in 2014 for risk simulations (Table A2).

For San Cristobal and Isabela islands, approximately USD 14.9 million have been allocated for infrastructure (46%) and community projects (54%) (Table A3). Funds that were invested are distributed as follows:

- Infrastructure: Approximately USD 6.8 million was invested for both islands for the design, construction, and maintenance of sustainable infrastructure to mitigate impacts caused by El Niño and strong precipitations events.
- Community: The government invested USD 8 million for a sustainable social and productive development through planification and land use.
- In 2016, USD 500 was allocated in 2016 in San Cristobal to implement strategies to face alert decreed by El Niño events.

3.3.4 What Needs to Be Done

For Santa Cruz, more research to better understand vulnerabilities and consequences of climate change to assist decision-making was recommended (d'Ozouville et al. 2010; Izurieta et al. 2018; Larrea and Di Carlo 2011; Sachs and Ladd 2010; Trueman and d'Ozouville 2010). While both the Charles Darwin Foundation (CDF) and the Galapagos Science Center (GSC) constantly measure various meteorological variables to predict future weather and develop climatic studies, there is still the need to improve data collection of current and future water supply and demand (Reyes et al. 2017), as well as possible future water sources (d'Ozouville 2008; d'Ozouville et al. 2008, 2010) in order to meet future water demands. Better water infrastructure planning and development is needed in Galapagos populated islands. Several studies have focused on characterizing water quantity (Reyes et al. 2015, 2016) and quality (López and Rueda 2010; Liu and d'Ozouville 2013; Mateus et al. 2019; Grube et al. 2020) providing useful information to help future water planning. Reyes et al. (2019) concluded that stakeholders think the most sustainable solutions for mitigating the impact on water supply are desalination plants, water meter installation, and leakage reduction (by replacing pipes and installing a control system that monitors pressure and flow in the pipes). However, other solutions were also discussed such as rainwater harvesting, gray water recycling, and water demand reduction which will not only mitigate water scarcity but also other environmental impacts (Reyes et al. 2017).

For San Cristobal, Izurieta et al. (2018) suggested the need to identify areas of priority research to assist in decision-making and Domínguez et al. (2016) the recommended characterization and quantification of cloud water interception for suitable water management policies. It was also suggested the implementation of fog/garúa capture infrastructure for domestic and irrigation uses (Echeverría Garcés et al. 2018) as well as alternatives for treatment, use, reuse, and final disposal of water at the home and municipal levels. During the workshops, the need for agricultural training and financing for technology implementation was proposed as well as an integrated water management program for hydrological basin management that includes analysis, monitoring, and infrastructure development.

Besides the need to identify areas of priority research to assist in decision-making (Izurieta et al. 2018) in Isabela, an integrated framework shared by local, national, and international stakeholders toward a more sustainable archipelago was also proposed (Gonzales et al. 2008).

3.4 Discussion

3.4.1 Evaluation of Proposed Actions Under Climate Change Scenario

Our results demonstrated that a significant amount of money has been invested and proposed toward climate change and water management issues in the archipelago. However, there is still the need to secure funding and guarantee the effectiveness on (i) research projects to improve hydrological data to better understand Galapagos' water balance and watershed characteristics of the islands as well as the development of new alternatives for water supply (i.e., desalinization plants, rainwater harvesting) to meet the already increased demand and possible future demand; (ii) implement programs for awareness about water use and conservation management; (iii) improve water storage and distribution for the agricultural and urban sector, and (iv) integrated water management plans that take into account climatic consequences and solutions.

While some studies have provided useful information toward the calculation of the islands' water balance (d'Ozouville et al. 2008; Sachs and Ladd 2010; Trueman and d'Ozouville 2010), there is still the need to better understand the flows and fluxes that enter and leave these systems (i.e., relationships between precipitation, runoff, and evapotranspiration). This will not only provide useful information for decision-making and water management but will also help explore alternatives for new water sources such fog catchers, rainwater harvesting, and desalinization plants or even look for new wells and aquifers. Capture and storage of storm water during extreme precipitation events will not only prevent urban flooding, soil erosion, beach destruction, and the contamination of water bodies and nonpoint source pollution (EPA 2005) but also provide water to meet human demands. Better understanding of the hydrogeology of the area will also highlight the need to protect and restore areas of hydrological importance.

Water conservation efforts depend on public awareness and understanding of the need for conservation. Beneficial reduction in water use, waste, and loss has been proven to be the most economical and environmentally protective management tool for meeting water supply challenges (Eneng et al. 2018). A broad, deep, and long-term persistent education on water conservation saving will not only provide citizens a better understanding of the importance of saving of water but establish the correct concept of its use based on scientific evidence. Furthermore, education and technical assistance programs for the public at large, municipal officials, and water suppliers are crucial to generating an understanding of current freshwater issues and creating acceptance to the implementation of water conservation efforts and accessibility.

To improve water storage and distribution for the agricultural and urban sector, several technical improvements and mechanisms can be proposed. Such techniques take into account reducing water losses by improving water infrastructure and strategies to encourage water conservation (pricing and water use protocols), for example, control leaks from pipe networks, installation and monitoring of water meters to secure water load, sewage pipeline expansion to improve sewage collection and reduce groundwater contamination, infrastructure to reuse recycled water, effective irrigation systems to improve water efficiency in agriculture, etc.

Desalinations plants have been proposed as a sustainable solution for mitigating the impact on water supply by future local population and tourism growth (Reyes et al. 2019). However, the main problem with desalination as a solution to provide freshwater is related to the high energetic cost and the initial cost of implementing the system. In Galapagos, as in many other oceanic islands, any solution that depends on large amount of energy constitutes a big challenge. Most of the energy that is used in Galapagos comes from fossil fuels which are imported from the mainland. Beside creating a bigger dependence on fossil fuels for the islands, importing oil to the islands from the continent can have detrimental environmental impacts such as the case in 2001 when there was a terrible oil spill from the ship Jessica (Accident of the Oil Tanker "JESSICA" off the Galapagos Islands (Ecuador) 2001). Therefore, any solution that relies in fossil fuels is an environmental threat unless the capacity of the island to produce renewable energy is increased in a significant manner. Unfortunately this means that any fossil fuel solutions such as desalinization plants must be carefully considered before they are implemented.

In terms of climate change, it is important to consider both El Niño and La Niña effects. In the last 10 years, droughts have been more of a problem than has been excessive rain. A survey made in 2019 (Barrera and Valverde 2019) demonstrated that 90% of the farmers have experienced big changes as a result of climate change and most of them were related with intensive periods of droughts (such as the one in 2015–2016) and higher temperatures rather than strong precipitation events. There have not been strong impacts of the warm cycle of El Niño since the 1980s and 1990s, and recent El Niño events have tended to be mild. Even when strong El Niño occurred, there was no strong effect in Galapagos. Some people claim that the ENSO is changing its nature, termed by some El Niño Modoki (Ashok et al. 2007; Kim et al. 2009).

Climate adaptation options to more likely intense and frequent ENSO events are needed to increase Galapagos' resilience to climate change. Intense and frequent La Niña events, characterized by extreme cooler and drier conditions (Trueman and d'Ozouville 2010), have endangering the water security of both the agricultural and urban sector. Warmer sea surface temperatures during El Niño events means more rainfall than normal and less nutrients to support marine ecosystems in the archipelago (d'Ozouville et al. 2010; Sachs and Ladd 2010). Recent coastal development has made the Galapagos much more vulnerable to changes in sea level, in particular to strong El Niño events such as the 1997–1998 event which led to increases in sea level by up to 45 cm (Sachs and Ladd 2010). In addition, the effect of warmer temperatures on *garúa*, the main source of water supply in the highlands that forms from low stratus clouds during the cool dry season (June to December), is likely to result in a reduction of *garúa* in the Galapagos. While more research is needed to fully understand the complexity of these interactions, actions to address these consequences must be undertaken.

3.4.2 Evaluation of Proposed Actions Under Climate Change and COVID-19 Scenario

It is important to understand the real impact of the COVID-19 pandemic in terms of climate change. Taking into account that transportation is the largest source of carbon emissions (Anenberg et al. 2019), COVID-19 lockdowns have resulted in significant reduction in global air pollution (Venter et al. 2020) due to fewer flights in the sky (Fouquet and O'Garra 2020), reduction of marine traffic (March et al. 2020), and decreased ground transportation (Z. Liu et al. 2020). No tourists in Galapagos means not only fewer flights, fewer boats transporting people from one island to the other, and fewer cars on the ground but also less demand for energy, food, and water. Having fewer tourists in natural areas and in the cities has given wildlife the opportunity to explore more areas (DPNG 2020). However, all these visible positive impacts are only temporary as they are due to the economic slowdown and human suffering. CO_2 emission reduction would need to occur over a long and sustained period of time in order for it to have a measurable impact on the climate (Venter et al. 2020).

There is also a strong relationship between water, climate change, and COVID-19. For example, access to adequate water is very difficult in Galapagos, especially in rural and agricultural areas. Additionally, the little existing access is being deteriorated due to climate change. In the case of COVID-19, it is very important to regularly wash your hands to combat the disease. To do so, there is the need to have access to sufficient, safe, and affordable water in addition to that required for cooking, hydration, and general sanitation (Armitage and Nellums 2020; Otto et al. 2020). "Water and climate are central to achieving global goals on sustainable development, climate change and disaster risk reduction" (Armitage and Nellums 2020). Investing in long-term water security and access to clean water and sanitation not only is essential for public health but also builds more resilient and thriving communities (Otto et al. 2020). Therefore, as places throughout the world come together to fight COVID-19 and rebuild the social and economic sectors, it is important to remember that water is a vital tool to strengthen communities and build resilience in the long term.

The climate crisis is, in some aspects, similar to the COVID-19 emergency, but in slow motion and much graver (Hepburn et al. 2020). The climate crisis will not give you the opportunity to stay at home for 2 months and then return to normal; rather it is irreversible in the medium and even in the long term. There are no vaccine and no social distancing measures that can help fix the problem. Climate change could however have a similar effect as COVID-19 as it can threaten the most profitable type of tourism activity which is international tourism. For example, climate change affects the survival of key charismatic species such as penguins, sea lions, marine iguanas, and sharks due to changes in the upwelling and water temperatures. In this way, the lack of financial resources that is now being caused by COVID-19 could be a good indicator of some of the economic and social effects that climate change can have in the long term. Nevertheless, the COVID-19 crisis has demonstrated that some governments can intervene decisively once the scale of an emergency is clear and public support is present (Hepburn et al. 2020).

Another similarity between climate change and COVID-19 response is that lack of transparency in the management of the funds available for both situations will result in the mismanagement of the resources that come to the islands. This mismanagement not only leads to the projects being poorly executed or not executed at all but also results in society developing lack of trust and low social capital which in the middle term affect the capacity of the society to execute new projects and implement any participatory strategy. Another related problem is that resources are being channeled outside of the local economy as outside organizations, governmental, private, and nongovernmental, charge large amounts to create studies and solutions that often are not implemented or inadequately implemented.

The COVID-19 pandemic will probably mean that the islands will need to be more self-dependent in the near future. This means that there will be greater pressure put on the local resources. Fishing and agriculture will probably be two of the sectors that will see an increase in the number of people involved in these two economic activities. Food security on the islands will be challenged by the fact that there will be less integration with the mainland, both because of disruption of the transportation system and also because of the lack of financial resources coming from tourism that allowed the locals to purchase outside goods. During the early days of COVID, bartering of subsistence agriculture has increased the importance of local production. This greater need for water in the agricultural sector will have to be met by improving current water infrastructure and operations (i.e., finding new water sources to provide water for small reservoirs) and better use of the water in the highlands (i.e., improving irrigation systems, reducing evapotranspiration, etc.).

The capacity of the coupled social environmental system to deal with climate change or the current pandemic will depend to a large degree on the resilience of the system. Water plays a key role in the capacity of the system to deal with the different threats. In the case of COVID-19, the flow of tourists stopped abruptly; as we write this chapter, approximately 70% of the economy of the islands has collapsed. In the urban areas, the collapse of the economy could mean that people no longer can afford to purchase clean water for cooking and drinking, and climate change could increase this problem even further. For the agricultural sector, water relates to assuring food security especially as the financial resources coming from tourism disappear and people become more dependent on locally produced food. Although climate change and COVID-19 have two very different time profiles, one being intense and most probably short lived and the other one being less intense but more long term, climate change could further threaten a system that has seen its resiliency already challenged. In the case of the urban sector, climate change can cause disruptions on the water supply and flooding with the consequent destruction of the infrastructure. Although the lack of tourists could mean short-term gains from the point of view of the natural ecosystems, there are also reasons to fear that in the long term, COVID and climate change could mean more trouble for the islands as they affect the flow of tourists. These can cause a vicious cycle as the decreasing number of tourist could result in unemployment and the revival of old threats such as illegal shark finning and sea cucumber gathering and the intensification of new ones such as the contraband of some emblematic species such as baby tortoises will further diminish the amount of nature-loving tourists that go to the islands.

Water is a key aspect of every socio-ecological system as it mediates between the natural and the human dimensions. We have seen that, by affecting the water supply and creating both excess or lack of water, both the biological and the human's systems can be affected. Although the effects of climate change may be difficult to predict, improvements in the material as well as the social and cultural conditions of the local communities may increase their resilience of the socio-ecological system and thus their chances of surviving new perturbations such as COVID-19 or climate change. Lack or excess of water will probably be one of the main challenges to fight both climate change and COVID-19. Improving water infrastructure to secure water quality and quantity such as reservoirs, flood control systems, and waste and potable water treatment plants are essential for the long-term socioecological resilience.

3.5 Conclusions

Galapagos' ecological and socials systems are evolving and changing at an accelerated rate. Disruptions threaten the resilience of the systems, and the residents must constantly adapt to the new conditions. This context of uncertainty and rapid transformation requires resilient, flexible, and adaptive systems that can rapidly accommodate to new conditions. The sustainability of Galapagos' unique ecosystems and the unique but fragile flora and fauna have started facing two very serious challenges in their recent history. In order for the current way of life of the Galapagos residents to survive, measures need to be taken to guarantee the long-term sustainability of the current system. The well-being of the local residents will guarantee the well-being of the unique environments that guarantee the flow of tourists. Water is a key element to guarantee both the viability of the agricultural sector and the health of the urban population. It is important that solutions to the current water situation are found. These solutions will not only require injecting more funds to the system, for as we have seen, the money per se is not always the main limitation and in some cases it may constitute a problem as it increases corruption and lack of trust. Instead changes in the political and social institutions could guarantee more accountability and better monitoring of the people involved in implementing the different measures.

Results suggest that although relatively large amounts of money have been allocated to increase the adaptive capacity of the Galapagos to water management in the context of climate change, much of these funds have not been actually adequately executed. There are different reasons for this to occur. However, transparency and accountability of funds and projects are key for the Galapagos socio-ecosystems to deal better with climate change. The systems in the Galapagos are characterized by mistrust and lack of open transparent and institutions. Information about the sources of funding and the way they are used are not readily available. Projects are often announced and then later cancelled or only executed in the incomplete manner. This has led to the current situation in which people have very little trust in the governmental and nongovernmental institutions that have failed to a large extent to implement realistic and effective solutions to the pressing issues related to the management and the availability of water of good quality both for the rural and the urban sector.

The presence of COVID-19, although not directly related to climate change, has resulted in a series of consequences in the islands. The principal one is the collapse of the tourism industry and thus of the Island economy. The long-term effects of the changes that the new pandemic is bringing will probably not be clear for many years, but resources to invest in adaptive measures to deal with possible effects of climate change and the water system will probably be restricted, and the resilience of the socio-ecological system will be lowered. We believe that well-directed and efficient investments in adaptive measures to climate change and pandemics, new infrastructure development, and the improvement of the capacity of the local communities to deal with these new challenges will be essential to assure the sustainability of these unique socio-environmental systems.

Apppendix

Table A1 Government plans and funding addressing climate change and water quantity issues in Santa Cruz, San Cristobal, and Isabela islands. The amount invested on each island for these plans are not specified

Initiative	Funding allocation	Year	Project status	PDOT description
Infrastructure	$ 528,474	2015	Executed	Design and assist in the implementation of an efficient, equitable, and sustainable integral mobility system in the province of Galapagos that guarantees the well-being of the population and the improvement in the quality of life of its inhabitants. Implement an alternative and sustainable mobility system. Responsible: Consejo de Gobierno del Régimen Especial de Galápagos (CGREG)
	$ 41,379	2016	94% executed by Dec.31, 2016	*Program: Infrastructure maintenance due to El Niño event*. Mitigation actions for impacts caused by the strong precipitation events. Responsible: CGREG
	$ 4,124,068	2016	99% executed by Dec.31, 2016	Reconstruction and maintenance of road network damaged due to El Niño, provide preventive maintenance to the roads and build infrastructure to mitigate impacts caused by the strong precipitation events. Responsible: CGREG
	$ 1,536,237	2015 2016	Executed	*Program: Sustainable infrastructure*. *Project 1.*Redesign, improve, and adapt ten docks along the visiting sites network
	$ 461,715	2017		*Project 2.*Redesign according to sustainable and safe infrastructure 15 visiting places from the ecotourist public use network of the Galapagos protected areas. Responsible: Galapagos National Park (PNG)

(continued)

Table A1 (continued)

Initiative	Funding allocation	Year	Project status	PDOT description
Research	$ 49,550	2015	Executed	Consulting studies to define areas of hydrogeological interest and exploratory drilling. Responsible: CGREG
Community	$ 222,810	2013	Executed	Training processes to improve the knowledge and economy of the population: Training for permanent and temporary residents on conservation of natural resources, environmental protection, and sustainable development. Responsible: CGREG
	$ 5,005,277	2017	95% executed by Dec.31, 2017	*Program: Sustainable development for Galápagos* *Project 1*. Stabilize population though optimal migration control and residency management in Galapagos *Project 2*. Plan, regulate, and control mobility within Galapagos *Project 3*. Increase and improve the road system in non-urban zones *Project 4*. Guarantee sustainable development of islands ecosystems through planification and land use. Responsible: CGREG
	$ 3,881,924	2018	99% executed by Dec.31, 2018	
	$ 12,217,866		59% executed by Dec.31, 2018	
	$ 3,745,605	2019	44% executed by Sept.30, 2018	
	$ 4,271,067		42% executed by Sept.30, 2018	
	$ 16,466,228		10% executed by Sept.30, 2018	
Total Invested	**$ 52,552,199**			

Sources: (a) "Plan Operativo Annual (POA)") (CGREG 2019); (b) Santa Cruz 2012–2027 (d'Ozouville et al. 2010; Larrea and Di Carlo 2011) (Gobierno Autonòmo Decentralizado Municipal de Santa Cruz 2012); (c) San Cristobal 2012–2016 (Gobierno Autonòmo Decentralizado Municipal de San Cristobal 2012), and; (d) Isabela 2012–2016 (Gobierno Autonòmo Decentralizado Municipal de Isabela 2012

Table A2 Government plans addressing climate change and water quantity issues in Santa Cruz Island

Initiative	Funding allocation	Year	Project status	PDOT description
Research	No information	2017	Running	Weather station: Measure and record various meteorological variables. Data used in numerical methods to predict future weather and climatic studies. Responsible: Charles Darwin Foundation (CDF)
	No information		Proposed	Contract for the monitoring of gases emitted to the atmosphere
Policy	$228,184	2012	Executed	Integrated water resource management plan to address future water scarcity. Responsible: Gobierno Autónomo Centralizado (GAD) Santa Cruz
	$20,000	2014	Proposed	*Program: Natural Risk Management Program*: *Project 1*: Risk drills to reduce the high threat level of the ecosystem vulnerability index to climate change to 23% and 69% until 2013. Responsible: Secretaría Técnica de Planificación y Desarrollo Sustentable (STPDS)
	$85,000	2014	Proposed	*Project 2*: Update the contingency plan (70% of funding), alert system (18% of funding); training (12% of funding). Responsible: Dirección de Obras Públicas (DOOPP)
	$37,000	2014	Executed	*Project 3*: risk simulations
	$35,000	2015	Proposed	*Project 4*: risk simulations (57% of funding) and early warning system (43% of funding). Responsible**:** STDPS-GR; DOOPP
	$268,970	2012–2013	Executed	Implement infrastructure for the capture, storage, and use of rainwater in the rural sector. Reservoirs in Miramar and Bellavista. Water tank in Santa Rosa. Responsible: GAD Santa Cruz
	$70,000,000	2013–2016	Executed	Implementing storage capacity for superficial water delivery to the agricultural sector (reservoirs and integral sewage and potable water system for Bellavista) and urban developments (Puerto Ayora and El Mirador)

(continued)

Table A2 (continued)

Initiative	Funding allocation	Year	Project status	PDOT description
Infrastructure	$17,000	2014 2015	Proposed	*Program: Natural Risk Management Program:* *Project 1*: risk signage to reduce threats and natural vulnerabilities Responsible: DOOPP. *Project 2*: for the study and design of the hiking road between Punta Estrada and Puerto Ayora. Responsible: STPDS
	No information	2016	Proposed	Implement storage capacity for superficial water delivery to the agricultural sector
	No information		Proposed	Maintenance of artificial wetlands
	$120,000	2014-2015	Proposed	*Program: Safety for all:* Relocate hospital and other institutions located in vulnerable areas. Risk management. Decrease vulnerability to natural disasters. Early warning system. Risk management training and simulation. Responsible: DOOPP -RIES, STPDS-RIES, DOOPP-STPDS, DOOPP-OOPP-RIES
	$37,000	2015	Executed	*Program: Safety for all:* Risk simulations
	$414,965	2016	Executed	Construction of 46 micro reservoirs for irrigation. Responsible: MAGAP
	$80,000	2019	Executed	Construction of a roof cover for the food area of the municipal market to provide protection against the effects of the climate. Responsible: Urban Planning and Land Management
	$60,000	2019	Proposed	Project: Acquisition of a weed crushing machine for the strengthening of the integral solid waste system. Responsible: Dirección de Gestión Ambiental
	$11,200	2019	Running	Consultancy for the construction of phase 2 of the landfill. Responsible: Dirección de Gestión Ambiental
	$15,200	2019	Executed	Contract for environmental audit of the construction and operation of the landfill project. Responsible: Dirección de Gestión Ambiental
Capacity building	$10,000	2016	Proposed	Ensure capacity building in the agricultural industry for food security

(continued)

Table A2 (continued)

Initiative	Funding allocation	Year	Project status	PDOT description
Community	$35,000	2019	Executed	Environmental education campaign including budget for communications. Responsible: Dirección de Gestión Ambiental
Total invested		**USD $ 70,127,519**		
Total proposed		**USD $ 347,000**		

Source: Santa Cruz 2012–2027 (Gobierno Autonòmo Decentralizado Municipal de Santa Cruz 2012)

Table A3 Government plans addressing water quality issues in San Cristobal Island and Isabela Island

Initiative	Funding allocation	Year	Project status	PDOT description
Policy	No information			**San Cristobal:** Natural Disaster Risk Management Program: Create a risk management control plan considering vulnerable areas for natural disasters and re-zoning
	$ 350,000	2012	Proposed	**San Cristobal:** Integrated Water Management: Retaining walls for "Frio and Playa de Oro" neighborhoods. Watershed monitoring and management. Responsible: GAD San Cristobal, Ministerio del Ambiente del Ecuador (MAE), ONG's
	$ 500	2016	Executed	**San Cristobal:** Provision of supplies for the implementation of strategies to face the alert decreed by El Niño events. Responsible**:** GAD San Cristóbal, Secretaría Técnica de Discapacidades
	No information	2016	No information	**San Cristobal:** Risk management 2016: Construction and application of prevention strategies to focus efforts on strategies against the risks of atmospheric and ocean origin. Responsible**:** GAD San Cristóbal
	No information			**Isabela:** Risk and Security: Develop a manual for natural risk management
	$1,500,000	2012	Proposed	**San Cristobal:** Water storage and distribution for agricultural sector. Responsible: GAD San Cristobal, Ministerio de Agricultura y Ganadería (MAGAP), CGREG

(continued)

Table A3 (continued)

Initiative	Funding allocation	Year	Project status	PDOT description
Infrastructure	$ 2,400,000	2014	Proposed	**San Cristobal:** Program for water conservation and management: construction of storm sewer networks. Responsible: GAD San Cristóbal, MIDUVI, ONG's
	$ 41,379	2016	Executed	**San Cristobal and Isabela:** Execution and maintenance of infrastructure and public works. Maintain the infrastructure that has been damaged due to the El Niño event. Provide preventive maintenance to public works to mitigate the negative impacts caused by torrential rains. Responsible: Consejo de Gobierno del Régimen Especial de Galápagos (CGREG)
	$ 4,124,068	2016	Executed	**San Cristobal and Isabela:** Reconstruction and maintenance of road network damaged due to El Niño, provide preventive maintenance to the roads and build infrastructure to mitigate impacts caused by the strong precipitation events
	$ 712,068	2016	Executed	**San Cristobal and Isabela:** Construction of 53 micro reservoirs in San Cristobal and 26 micro reservoirs in Isabela. Responsible: MAGAP
	$ 1,997,952	2015–2017	Executed	**San Cristobal and Isabela:** Design and build sustainable infrastructure. 1. Redesign, improve, and adapt ten docks along the visiting sites network. 2. Redesign according to sustainable and safe infrastructure 15 visiting places from the ecotourist public use network of the Galapagos protected areas. Responsible: Galapagos National Park (PNG)

(continued)

Table A3 (continued)

Initiative	Funding allocation	Year	Project status	PDOT description
Community	No information			**San Cristobal:** Consolidate plans for ecological urban centers
	$ 5,005,277	2017	Executed	**San Cristóbal and Isabela:** Sustainable social and productive development in Galapagos. Responsible: CGREG
				1.Stabilize population though and optimal migration control and residency management in Galapagos. Plan, regulate, and control mobility within Galapagos
	$ 3,032,803	2018		2.Increase and improve the road system in non-urban zones. Guarantee sustainable development of islands ecosystems through planification and land use
	No information			**Isabela:** Build an agroforestry and silviculture system starting with education about climatic consequences
Capacity Building	No information			**Isabela:** Capacity building in technology for farmers
Research	No information			**Isabela:** Develop hydrogeological studies and inform farmers of crop rotation
Total invested		**USD $ 14,914,137 for both islands. Additional $500 for San Cristobal only**		
Total proposed		**USD $ 4,250,000 for San Cristobal only**		

Sources: San Cristobal 2012–2016 (Gobierno Autonòmo Decentralizado Municipal de San Cristobal 2012) and Isabela 2012–2016 (Gobierno Autonòmo Decentralizado Municipal de Isabela 2012)

References

Accident of the Oil Tanker “JESSICA” off the Galapagos Islands (Ecuador) (Final Report to European Commission DG Environment ENV.C.3.) (2001) Civil Protection.

Adelinet M, Fortin J, d’Ozouville N, Violette S (2008) The relationship between hydrodynamic properties and weathering of soils derived from volcanic rocks, Galapagos Islands (Ecuador). Environ Geol 56(1):45–58

Ahmadi M, Sharifi A, Dorosti S, Jafarzadeh Ghoushchi S, Ghanbari N (2020) Investigation of effective climatology parameters on COVID-19 outbreak in Iran. Sci Total Environ 729:138705

Anenberg S, Miller J, Henze D, Minjares R (2019) A global snapshot of the air pollution-related health impacts of transportation sector emissions in 2010 and 2015 (ICCT Report, p. 55). International Council on Clean Transportation

Armitage R, Nellums LB (2020) Water, climate change, and COVID-19: Prioritizing those in water-stressed settings. The Lancet Planetary Health 4(5):e175

Ashok K, Behera SK, Rao SA, Weng H, Yamagata T (2007) El Niño Modoki and its possible teleconnection. J Geophys Res 112(C11)

Barrera V, Valverde M (2019) Productividad y sostenibilidad de los sistemas de producción agropecuaria de las islas Galápagos-Ecuador (Libro Técnico No. 174; p. 228). ARCOIRIS Producción Gráfica

CGREG, – Consejo de Gobierno del Régimen Especial de Galápagos (2016) Plan de Desarrollo Sustentable y Ordenamiento Territorial del Régimen Especial de Galápagos. –Plan Galápagos. Consejo de Gobierno del Régimen Especial de Galápagos

CGREG, – Consejo de Gobierno del Régimen Especial de Galápagos (2019) Transparencia: Planes y programas de ejecución. Consejo de Gobierno del Régimen Especial de Galápagos

CISPDR, – Changjiang Institute of Survey Planning Design and Research (2015) Plan Reginal de los Recursos Hídricos de las Islas Galápagos. Changjiang Institute of Survey Planning Design and Research (CISPDR)

d'Ozouville, N. (2007). Agua dulce: La realidad de un recurso crítico. Aspectos sobre biodiversidad y recursos biofísicos. (150 Informe Galápagos 2006–2007; p. 13). FCD, PNG & INGALA.

d'Ozouville, N. (2008). Manejo de recursos hídricos: Caso de la cuenca de Pelican Bay. (INFORME GALÁPAGOS 2007–2008; p. 10). Galapagos Conservancy.

d'Ozouville N, Deffontaines B, Benveniste J, Wegmüller U, Violette S, de Marsily G (2008) DEM generation using ASAR (ENVISAT) for addressing the lack of freshwater ecosystems management, Santa Cruz Island, Galapagos. Remote Sens Environ 112(11):4131–4147

d'Ozouville N, Di Carlo G, Ortiz F, De Konin F, Henderson S, Pidgeon E (2010) Galapagos in the face of climate change- considerations for biodiversity and associated human wel-being. (GALAPAGOS REPORT 2009–2010). Conservation International

Domínguez CG, Pryet A, García Vera M, Gonzalez A, Chaumont C, Tournebize J, Villacis M, d'Ozouville N, Violette S (2016) Comparison of deep percolation rates below contrasting land covers with a joint canopy and soil model. J Hydrol 532:65–79

DPNG – Direccion Parque Nacional Galapagos (2017) Informe Anual de Visitantes a las Áreas Protegidas de Galápagos 2017. Dirección del Parque Nacional Galápagos

DPNG – Direccion Parque Nacional Galapagos (2020) Se incrementa avistamiento de cetáceos en Canal Bolívar. Parque Nacional Galapagos, Ecuador

Echeverría Garcés P, Domínguez C, Villacís M, Violette S (2018) Potencial de la captura de niebla para uso doméstico rural y riego en la Isla San Cristóbal, Galápagos, Ecuador. [Thesis work, Escuela Politécnica Nacional]

El Comercio (2019) El servicio de agua es uno de los retos. Diario EL COMERCIO. https://www.elcomercio.com/tendencias/servicio-agua-retos-galapagos-ecosistema.html

Eneng R, Lulofs K, Asdak C (2018) Towards a water balanced utilization through circular economy. Manag Res Rev 41(5):572–585

EPA (2005) National Management Measures to Control Nonpoint Source Pollution from Urban Areas. (EPA-841-B-05-004). Environmental Protection Agency

Fouquet R, O'Garra T (2020) The behavioural, welfare and environmental impacts of air travel reductions during and beyond COVID-19. Centre for Climate Change Economics and Policy Working. Centre for Climate Change Economics and Policy, Working Paper 372/Grantham Research Institute on Climate Change and the Environment Working Paper 342. London: London School of Economics and Political Science, 57.

GAD Isabela, – Gobierno Autonòmo Decentralizado Municipal de Isabela (2012) Plan de Desarrollo y Ordenamiento Territorial_Cantón Isabela: PDOT-Isabela. Gobierno Autonòmo Decentralizado Municipal de Isabela, p 281

GAD San Cristobal, – Gobierno Autonòmo Decentralizado Municipal de San Cristobal (2012) Plan de Desarrollo y Ordenamiento Territorial_Cantón San Cristobal: PDOT-San-Cristobal. Gobierno Autonòmo Decentralizado Municipal de San Cristobal, p 322

GAD San Cristobal, – Gobierno Autonòmo Decentralizado Municipal de San Cristobal (2017) Ordenanza Presupuestaria del Gonierno Autónomo Desentralizado (GAD) Municipal del Cantón San Cristóbal para el ejercicio económico del año 2018. Gobierno Autonòmo Decentralizado Municipal de San Cristobal

GAD Santa Cruz, – Gobierno Autonòmo Decentralizado Municipal de Santa Cruz (2007) Alcantarillado Sanitario y Tratamiento Aguas Residuales de la Expansión de Puerto Ayora. Puerto Ayora, Ecuador, Gobierno Autonòmo Decentralizado Municipal de Santa Cruz

GAD Santa Cruz, – Gobierno Autonòmo Decentralizado Municipal de Santa Cruz. (2012). Plan de Desarrollo y Ordenamiento Territorial_Cantón Santa Cruz: PDOT-Santa Cruz. (p. 214). Gobierno Autonòmo Decentralizado Municipal de Santa Cruz. b.ec/wp-content/uploads/downloads/2013/08/PDOT-Santa-Cruz-2012_2_primero.pdf

Gonzales Iñiguez AA (2013) Cálculo del balance hídrico a nivel del suelo en la zona agrícola de la cuenca pelikanbay en la isla Santa Cruz-Galápagos, Ecuador. [Tesis Ingenieria Civil y Ambiental (ICA), Escuela Politécnica Nacional]

Gonzales JA, Montes C, Rodriguez DJ, Tapia W (2008) Rethinking the Galapagos Islands as a complex social-ecological system: Implications for conservation and management. Ecol Soc 13(2):13

Grube AM, Stewart JR, Ochoa-Herrera V (2020) The challenge of achieving safely managed drinking water supply on San Cristobal island, Galápagos. Int J Hyg Environ Health 228:113547

Hepburn C, O'Callaghan B, Stern N, Stiglitz J, Zenghelis D (2020) Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? Oxford Rev Economic Policy

INEC (2015) Análisis de resultados definitivos Censo de Población y Vivienda Galápagos 2015.

Izurieta A, Delgado B, Moity N, Calvopiña M, Cedeño I, Banda-Cruz G, Cruz E, Aguas M, Arroba F, Astudillo I, Bazurto D, Soria M, Banks S, Bayas S, Belli S, Bermúdez R, Boelling N, Bolaos J, Borbor M et al (2018) A collaboratively derived environmental research agenda for Galapagos. Pac Conserv Biol 24:168

Kim H-M, Webster PJ, Curry JA (2009) Impact of shifting patterns of Pacific Ocean warming on North Atlantic tropical cyclones. Science 325(5936):77–80

La Hora (2016) Luego de 43 años, la Isla Santa Cruz tendrá agua por tuberías. La Hora. https://lahora.com.ec/noticia/1101951818/luego-de-43-aos-la-isla-santa-cruz-tendr-agua-por-tuberas

Larrea I, Di Carlo G (2011) Climate Change Vulnerability Assessment of the Galápagos Islands. WWF & Conservation International

Liu J, d'Ozouville N (2013) Contaminación del agua en Puerto Ayora: Investigación interdisciplinaria aplicada utilizando Escherichia coli como una bacteria indicador (pp. 76–83). Informe Galápagos 2011–2012; DPNG, CGREG, FCD and GC.

Liu Z, Ciais P, Deng Z, Lei R, Davis SJ, Feng S, Zheng B, Cui D, Dou X, He P, Zhu B, Lu C, Ke P, Sun T, Yue X, Wang Y, Lei Y, Zhou H, Cai Z et al (2020) [Submitted v3]. Near-real-time data captured record decline in global CO2 emissions due to COVID-19. Cornell University Founded A.D. 1965. ArXiv:2004.13614 (Econ) 45

López J, Rueda D (2010) Water Quality Monitoring System in Santa Cruz, San Cristóbal, and Isabela (No. 2009–2010). Galapagos National Park

Ma Y, Zhao Y, Liu J, He X, Wang B, Fu S, Yan J, Niu J, Zhou J, Luo B (2020) Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. Sci Total Environ 724:138226

MAGAP, M. de A. y G (2016) Construyen microreservorios para dotar de agua a agricultores y ganaderos de Galápagos. Ministerio de Agricultura y Ganadería

MAGAP, M. de A. y G (2019) Informe de Gestión: Rendición de Cuentas 2018. Período 1 de enero al 31 de diciembre de 2018. Dirección Distrital de Galápagos

March, D., Metcalfe, K., Tintoré, J., & Godley, B. (2020). Tracking the global reduction of marine traffic during the COVID-19 pandemic [Preprint]. In Review.

Mateus MC, Guerrero CA, Quezada G, Lara D, Ochoa-Herrera V (2019) An Integrated Approach for Evaluating Water Quality between 2007–2015 in Santa Cruz Island in the Galapagos Archipelago. 11(5):28

Mateus MC, Valencia M, Quiroga D, DiFrancesco K, Ochoa-Herrera V, Gartner T (2020) Barriers and mechanisms for achieving water quality improvements in Galapagos [Manuscript submitted for publication]. College of Science and Engineering, Universidad San Francisco de Quito (USFQ)

Otto B, Kuzma S, Strong C, Chertock M (2020) Combating the Coronavirus Without Clean Water. World Resources Institute (WRI). https://www.wri.org/blog/2020/04/coronavirus-water-scarcity-hand-washing

Percy MS, Schmitt SR, Riveros-Iregui DA, Mirus BB (2016) The Galápagos archipelago: A natural laboratory to examine sharp hydroclimatic, geologic and anthropogenic gradients: A natural laboratory to examine sharp hydroclimatic, geologic and anthropogenic gradients. Wiley Interdisciplinary Reviews: Water

Reyes M, Trifunović N, Sharma S, Kennedy M (2015) Water supply and demand in Santa Cruz Island – Galápagos Archipelago. Int Water Technol 10

Reyes MF, Trifunović N, Sharma S, Kennedy M (2016) Data assessment for water demand and supply balance on the island of Santa Cruz (Galápagos Islands). Desalin Water Treat 57(45):21335–21349

Reyes M, Trifunović N, Sharma S, Behzadian K, Kapelan Z, Kennedy M (2017) Mitigation options for future water scarcity: a case study in Santa Cruz Island (Galapagos Archipelago). Water 9(8):597

Reyes M, Petričić A, Trifunović N, Sharma S (2019) Water management strategies using multi-criteria decision analysis in Santa Cruz Island (Galapagos Archipelago). Scientific Rev 56:112–123

Sachs JP, Ladd SN (2010) Climate aOceanography 0f Tthe Galapagos in the 21st Century: Expected Changes and Research Needs. 5.

SENPLADES (2013) Proyectos de Inversión Pública en Galápagos. Secretaria Nacional de Planificación y Desarrollo

Trueman M, d'Ozouville N (2010) Characterizing the Galapagos terrestrial climate in the face of global climate change. Galapagos Res 12

Venter ZS, Aunan K, Chowdhury S, Lelieveld J (2020) COVID-19 lockdowns cause global air pollution declines. Proc Natl Acad Sci 117(32):18984–18990

Violette S, d'Ozouville N, Pryet A, Deffontaines B, Fortin J, Adelinet M (2014) Hydrogeology of the Galápagos Archipelago: An Integrated and Comparative Approach Between Islands. Galápagos A Nat Lab Earth Sci Geophys Monogr 204:167–185

Wang M, Jiang A, Gong L, Luo L, Guo W, Li C, Zheng J, Li C, Yang B, Zeng J, Chen Y, Zheng K, Li H (2020) Temperature significant change COVID-19 Transmission in 429 cities [Preprint]. Infectious Diseases (except HIV/AIDS)

Wu X, Nethery RC, Sabath BM, Braun D, Dominici F (2020) Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study [Preprint]. Epidemiology. https://doi.org/10.1101/2020.04.05.20054502