PRIORITY AREAS FOR IRRIGATION INVESTMENTS IN BELIZE

FAO INVESTMENT CENTRE

COUNTRY INVESTMENT HIGHLIGHTS
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This publication was prepared drawing on the experience, knowledge and insights gained during the implementation of the Technical Cooperation Programme (TCP) project “Sustainable agriculture development resilient to climate change through irrigation and drainage planning” by the Food and Agriculture Organization of the United Nations (FAO) between June 2019 and June 2021. The project resulted in the elaboration of a multi-criteria framework of analysis for irrigation and drainage to tackle climate change impacting agriculture production in Belize.

The TCP was implemented by an FAO team led by Roble Sabrie, Economist, FAO Investment Centre, and included Luis Loyola, former Irrigation and Rural Infrastructure Engineer, FAO Investment Centre and now Senior Irrigation and Drainage Specialist at the World Bank, Jacopo Monzini, Senior Natural Resources Officer, FAO Investment Centre, Santos Chicas, GIS Expert Consultant, Carlos Itza, Agronomist Consultant, and Lucien Chung, Irrigation Engineer Consultant, who assisted the team with the analyses and findings for the preparation of this publication.

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### Abbreviations

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<th>Description</th>
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<tr>
<td>BAIMS</td>
<td>Belize Agriculture Information Management System</td>
</tr>
<tr>
<td>CHIRPS</td>
<td>Climate Hazards Group InfraRed Precipitation with Station data</td>
</tr>
<tr>
<td>CIAT</td>
<td>International Center for Tropical Agriculture</td>
</tr>
<tr>
<td>CSA</td>
<td>climate-smart agriculture</td>
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<tr>
<td>ETa</td>
<td>actual evapotranspiration</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>GIS</td>
<td>geographic information system</td>
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<tr>
<td>I&amp;D</td>
<td>irrigation and drainage</td>
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<td>IPF</td>
<td>Infrastructure Prioritization Framework</td>
</tr>
<tr>
<td>IRR</td>
<td>internal rate of return</td>
</tr>
<tr>
<td>MAFFESDI</td>
<td>Ministry of Agriculture, Forestry, Fisheries, the Environment, Sustainable Development and Immigration</td>
</tr>
<tr>
<td>NAFP</td>
<td>National Agriculture and Food Policy</td>
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<tr>
<td>NPV</td>
<td>net present value</td>
</tr>
<tr>
<td>PET</td>
<td>potential evapotranspiration</td>
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<td>USDA</td>
<td>United States Department of Agriculture</td>
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Executive summary

Belize, a Caribbean nation facing increasing climate change threats to its vital agriculture sector, demands immediate action to improve its climate resilience. This study emphasizes the critical necessity of prioritizing climate-resilient irrigation and drainage (I&D) investments, providing a contribution to the nation's ongoing efforts against these challenges.

Despite being a significant contributor to the country's GDP, Belize's agriculture remains highly vulnerable to climate-induced events, such as floods, droughts, and hurricanes. Aligned with Belize's climate resilience commitments articulated in the National Agriculture and Food Policy (NAFP) 2015–2030 and the National Climate Resilience Investment Plan, this study develops a multi-criteria framework. The framework is designed to identify and prioritize strategic irrigation and drainage (I&D) investments with a primary focus on elevating agricultural productivity, bolstering resilience, and facilitating year-round fresh produce delivery. The study, however, acknowledges existing data limitations, particularly concerning hydrological surface water sources and groundwater data, underscoring the imperative need for enhanced accuracy and reliability in assessing water availability and potential usage patterns.

This study shows insights into the pressing requirement for climate-resilient I&D investments within Belize's agricultural landscape. The findings underscore the paramount importance of targeted investments in collaboration with relevant stakeholders to effectively mitigate climate risks. The conclusions emphasize the necessity for ongoing collaboration, improved data availability, and strategic resource allocation to fortify Belize's agriculture sector against the multifaceted challenges posed by climate change.
Belize is a Caribbean country located on the northeastern coast of Central America. It borders Mexico to the north, the Caribbean Sea to the east, and Guatemala to the west and south. Situated at an average of 173 metres above sea level, it spans an area of 22,970 square kilometres with a population of 397,621 (2020).

Agriculture is critical to Belize's development and is a major source of growth, employment, foreign exchange earnings, in addition to food and nutrition security. In other words, the agriculture sector is important both economically and socially. Over the period 2015–2017, agriculture contributed to 9.5 percent of the gross domestic product on average. Total agricultural exports amounted to USD 203 million, corresponding to 88 percent of total exports. The leading agricultural exports were sugar (23 percent), orange concentrate (21 percent), banana (20 percent), papayas (4 percent), and animal feed (3 percent). On the other hand, agricultural imports were very modest, averaging only USD 15 million per year during the same period. The leading agricultural imports included wheat, corn (mainly corn flour), malt, potatoes, and rice. In addition, live cattle were imported as breeding stock, and specialty cuts of meat were imported for the tourism market (World Bank, 2018).

Agriculture in Belize is susceptible to weather variability and vulnerable to climate hazards such as hurricanes, floods, and droughts. Weather variability caused by climate change will likely increase over time, potentially resulting in yearly rainfall decreases ranging from about 7 percent in the northern zone to around 10 percent in the southern zone. The most detrimental effects on agriculture are expected to come from increased variability in the seasonal distribution of rainfall, leading to more frequent droughts and floods. Additionally, projected rises in temperature of 1.3 °C by the 2030s will increase stress on crops and livestock, impacting agricultural systems, forcing changes in management practices, and threatening food production (World Bank, 2018).

Belize is working tirelessly to build its resilience to climate change, especially in the areas of irrigation, drainage, and water management. This effort is reflected in both the National Agriculture and Food Policy (NAFP) of Belize 2015–2030 and the National Climate Resilience Investment Plan. Notwithstanding these efforts, climate change remains a significant threat to Belize, and the Caribbean is still classified as among one of the most vulnerable regions in the world. Exposure and the sensitivity of the country to extreme
events, including droughts and more intense hurricanes as well as sea level changes have increased. Projections for the region expect the current trends to continue during the course of this century. Air and ocean surface temperatures show a constant increase, including a higher frequency of temperature extremes across the region. Concerning precipitations, trends (1989–2017) are less linear and homogenous mostly because of the diverse geography and topography of the region. Nonetheless, precipitation patterns that defined the times for agriculture and fishery over centuries have changed.

In sum, the most likely effects of climate change in Belize include the following:

- sea level rise: the country’s geographic location leaves it exposed to the risk of rising sea levels;
- more frequent and more intense tropical storms that will lead to recurrent flooding, resulting in human and material loss, including substantial losses within the agriculture sector;
- decreased precipitation throughout the country (ranging from 6.9 percent in the northern zone to 10 percent in the southern zone);
- increased variability in the seasonal distribution of rainfall, resulting in greater frequency of droughts, floods, and landslides triggered by extreme precipitation;
- increased temperature (annual mean temperature rising by 1.3 °C in the 2030s and by 1.7–1.8 °C in the 2050s) in all districts, with the highest increases occurring during the months from March to May.

The effects of climate change pose a significant threat to Belizean agriculture vis-à-vis agricultural production and productivity, especially for smallholder farmers who are the most vulnerable and stand to suffer the most. In February 2018 alone, small- and medium-size producers suffered losses of more than 1000 hectares because of excessive moisture and flooding. Lost crops included grains and pulses (corn and beans) worth USD 1.19 million, vegetables worth USD 0.68 million, and plantain worth USD 0.31 million, for a combined total of USD 1.9 million (MAFFESDI, 2018). The vast majority of these farmers were not insured against these events, which resulted in loss of income and created crop shortages, triggering price increases in the market that also affected consumers. Meanwhile, road infrastructure was damaged extensively in many areas, transportation costs rose and food prices increased.

In 2019, a severe drought caused a slowdown in economic growth. Agriculture and electricity production from water were the areas most affected. A preliminary analysis by the Ministry of Agriculture estimated the agricultural loss experienced by farmers due to the drought at USD 38.5 million (Ministry of Agriculture, 2019). The sugar industry in particular was badly hit, and the government had to intervene with financial support for producers.

Changes in the frequency and intensity of tropical cyclones in the future are likely to become more intense, bringing heavier precipitation and probable stronger winds. In this regard, the implementation of planned surface drainage on irrigated lands contributes to eliminating excessive duration of ponding, or to direct excess-surface runoff to a safe outlet.
Promoting climate resilience investment in agriculture is one of the main objectives of the National Agriculture and Food Policy (NAFP) 2015–2030 (Ministry of Agriculture, 2015), which is reflected in Pillars 1 and 4. Strategic Objective 1.6 of the first pillar of the strategy involves sustainable production, productivity, and competitiveness, in other words, improved infrastructure to support a competitive agriculture including rural feeder roads, adequate port facilities, storage facilities, and water systems for agriculture, and other. Strategic Objective 4.1, which is part of Pillar 4, entails sustainable agriculture and risk management, that is, the promotion of best practices in Digital Rights Management and Climate Change Adaptation.1

Based on the aforementioned, and as part of the Belize Climate-Smart Agriculture Prioritization Framework (CSA-PF),2 irrigation and drainage (I&D) investments have the potential to contribute to Belize's agricultural development goals by: (i) sustainably increasing productivity; (ii) enhancing resilience; and (iii) allowing farmers to deliver fresh vegetables and fruits during the dry season (which precedes and overlaps with the relatively high demand generated by the busiest tourist season).

The Government of Belize requested the assistance of the Food and Agriculture Organization of the United Nations (FAO) to help strengthen its approach to managing the impacts of climate change, particularly hurricanes, floods, and drought, on agriculture production.

The request fits into one of the four priority areas identified for collaboration between FAO and Belize over the period 2016–2019, which is “promoting sustainable and resilient food systems” (FAO, 2015).

To fulfill its assignment, FAO applied an innovative methodology based on the preparation of a multi-criteria framework. The main focus of this report is to present the methodology developed by FAO for identifying and prioritizing I&D investments in order to help policymakers and private sector's investors target I&D investment resources. Support from FAO would complement the World Bank, the International Fund for Agricultural Development (IFAD) and Caribbean Development Bank (CDB) ongoing programmes and support aimed at promoting climate change resilience in agriculture.

In this study, it is crucial to acknowledge the limitations of the methodologies to ensure the integrity and reliability of the findings. One significant limitation lies in data availability, particularly concerning hydrological surface water sources and groundwater data. The lack of comprehensive and up-to-date information on these water sources posed challenges to making an accurate assessment of the overall water availability and potential usage patterns. This analysis is based on remote sensing and secondary information from reputable sources. While these data provided valuable insights, they are not without limitations and potential inaccuracies. Improving data availability should be a priority in future studies, and establishing robust monitoring networks for surface water and groundwater resources would enhance the accuracy and reliability of our assessments. Additionally, fostering collaboration with relevant authorities and institutions for data sharing can further enrich the data pool and improve the comprehensiveness of future analyses.

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2 Prepared by the Government of Belize (GOB), through the Ministry of Agriculture, Fisheries, Forestry, the Environment, Sustainable Development and Immigration (MAFFESDI) with funding from the World Bank, in partnership with the International Center for Tropical Agriculture (CIAT) and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
The information and analysis presented in this publication on multidimensional analysis to identify priority areas for irrigation investment are intended to serve as a valuable contribution to the existing literature and available methods in the field of agricultural development. However, it should be considered as an informational resource and not as an authoritative or exhaustive source on the subject.

The publication is intended to foster knowledge sharing and dialogue within the academic and professional community working on irrigation investment and related fields. The authors hope that this contribution will stimulate further research, innovation, and collaboration to address the global challenges of sustainable agricultural development and water resource management.

The proposed technical approach focuses on investment support for climate proofing and adaptation of national infrastructures that have become increasingly important, given the intensifying climate-related risks. The exposure of the irrigation and rainfed crops to climate variability and change are expected to increase at the local and regional scale. These factors should be considered during the identification and preparation of an I&D strategy, and include the identification and prioritization of infrastructural investments such as:

- rehabilitation, improvement, modernization of existing irrigated schemes;
- water-harvesting structures (from rainwater and surface water runoff);
- on-farm irrigation technology as drip irrigation systems;
- investments in expansion of irrigation; and
- drainage systems.

The primary objective of this publication is to develop a comprehensive multi-criteria framework designed to identify and prioritize investments in I&D projects. This framework serves as a valuable tool to help policymakers and private sector investors make informed decisions and effectively allocate I&D investment resources. By utilizing this framework, stakeholders can gain deeper insights into the potential impacts and outcomes of various investment options, thus enabling them to target their resources more strategically and efficiently. The
multi-criteria approach takes into account a diverse set of factors, including economic viability, social impact, environmental sustainability, and technical feasibility among others. As a result, the framework facilitates the design of context-specific investment portfolios tailored to the unique needs and conditions of each project, leading to more successful and impactful I&D initiatives. The utilization of this methodology empowers decision-makers to foster sustainable development, drive economic growth, and improve the overall well-being of communities and regions. In particular, the methodology targets the future investments of international financing institutions in I&D in Belize, and aims to provide a coherent framework of analysis for the country. The publication focuses on water use for agriculture and does not delve into the dynamics of water allocation and competition among various sectors.

To fulfill its assignment, FAO applied an innovative methodology based on the combination of ground data (such as national statistics, national agrarian census, cadaster, interviews) with advance remote sensing and data processing tools such as EarthMap, Google Engine, Aquastat and Aquacrop. The combination of these different tools and applications will allow for mapping and quantifying the interaction between different dimensions and variables. In this framework, the selected methodology was designed to: (i) gather, evaluate and systematize technical, environmental and logistic information, with a view to making informed decisions on activities that should inform the design and implementation of a national irrigation and drainage master plan; (ii) develop digital support for the identification and selection of priority areas to promote the expansion of Belize’s national irrigation and drainage systems, without compromising natural resources, and also factoring in climate change trends and projection; and (iii) conduct preliminary identification studies for improving irrigation and drainage systems on priority and pre-selected areas.

The analysis combined the use of various sources of data covering a period ranging between 40 and 10 years, which offers a relevant view of trends in temperature, precipitation, water deficit, surface water transition, soils, land use, and other variables.

Currently, the approach to rural infrastructure prioritization in Belize is not well defined. As a result, there is a need for evidence-based decision support that is consistent, pragmatic, and responsive to the particular needs and current capacities of the country. Systematic project prioritization requires a clearly defined framework of analysis that is rigorous enough to incorporate multiple policy dimensions (technical, financial, economic, social, environmental) while remaining practical to implement. Good practice suggests that economic and strategic project appraisals and feasibility studies provide a good basis for project prioritization via societal net present value (NPV) as a ranking metric.” The reality, however, is that technical capacity, financial resources and time are often limited and as a result cannot adequately support extensive economic analysis across full project sets. There is a need for evidence-based infrastructure decision support that is consistent and data-driven; in order to consider the relative efficiency and efficacy of the projects. At the same time, the approach must be pragmatic and responsive to the needs and current capacities of the government.
The proposed Infrastructure Prioritization Framework (IPF) is a multi-criteria decision support tool designed to help governments compare alternative investment scenarios, optimize sector investments, and ultimately select the most appropriate projects for the achievement of stated social, economic and environmental objectives of the country. The IPF, developed by the World Bank, was furthermore created to help governments prioritize infrastructure investments with limited resources, multiple policy goals, and conditions of uncertainty.

A multi-criteria approach serves this purpose through the selection of criteria that specifically reflect considerations of effectiveness and value, as well as sector and sustainable development policy goals. The IPF not only captures the strengths of multi-criteria decision approaches, but it also allows for the use of inputs from cost-benefit analysis. Establishing a clear prioritization strategy also affords legitimacy to government decisions by providing a transparent and objective process.

Implementing the IPF is relatively straightforward, following five steps:

1. selecting decision criteria;
2. gathering project-level criteria data;
3. calculating social-environmental and financial-economic composite indicators;
4. plotting projects and budget limits; and
5. selecting projects.

In the case of Belize, as part of the prioritization process for the selection of priority watersheds the FAO team adapted the IPF framework, calculating only the social-environmental indicators based on climate, natural resources, and socioeconomic criteria. The indicators were calculated by defining the specific critical variables using the results and inputs from the different platforms and tools illustrated below.

To implement the methodology, it was necessary to make the following four key decisions:

1. define criteria to be included in the socioenvironmental indexes;
2. gather watershed available criteria data;
3. define a weighting methodology to combine variables and calculate scores; and
4. establish decision criteria for ranking priority watersheds.
APPLICATION OF PRIORITIZATION METHODOLOGY

Selecting decision criteria
Thanks to the reported data and analysis, the project scored a series of indicators to characterize watersheds and their agriculture areas from an environmental (climate and natural resources) and agro-socioeconomic perspective (Figure 1).

The watershed approach level analysis was agreed to and adopted by Belizean authorities, as it was considered better adapted to water analysis than a standard administrative level analysis.

Gathering project level criteria data
A broad range of remote sensing data was systematized to understand the trends of the historical climatic data and assess impacts in the different watersheds (Please refer to Annex 1).
For each of the agriculture areas per watershed the following data was processed:

- agriculture areas per watershed: source Ecosystems Map of Belize 2017;
- total area and land cover disaggregation (Land Cover, Sources: 10m Map of Central America 2018 and IPCC categories based on ESA CCI [2018]);
- land productivity dynamic: land productivity dynamics data is derived from NDVI product of MODIS/Terra Vegetation Indices. The dynamics in the land productivity indicator is related to changes in the health and productive capacity of the land, and reflects the net effects of changes in ecosystem functioning due to changes in plant phenology and biomass growth, where declining trends are often a defining characteristic of land degradation;
- digital elevation model: elevation and slopes – slopes class groups based on the elevation data from SRTM Digital Elevation Model. The slope is derived from the terrain algorithm in the Google Earth Engine, which calculates the gradient using the 4-connected neighbours of each pixel located within each agriculture area;
- soils: soil texture classes (United States Department of Agriculture [USDA] system) for six soil depths (0, 10, 30, 60, 100 and 200 cm). To account for the different soils' ability to infiltrate, USDA Natural Resources Conservation Service divided soils into four hydrologic soil groups. They are defined as follows:
  - group A: low runoff potential;
  - group B: soils with moderate infiltration rates;
  - group C: soils with slow infiltration rates when thoroughly wetted;
  - group D: high runoff potential, soils with very slow infiltration rates when thoroughly wetted;
- climatic water deficit: climatic water deficit is the difference between the potential and the actual evapotranspiration (Eta) (PET-AET). Source: M–D16A2 MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500 m SIN Grid;
- precipitations: the 1981–2020 quasi-global rainfall dataset incorporates 0.05°C resolution satellite imagery with in situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Source: Climate Hazards Group InfraRed Precipitation with Station data [CHIRPS]);
- frequency of data can provide different information to the modelling.\footnote{Daily data can provide more detailed information on crop water deficits and irrigation needs on a day-to-day basis. This level of detail can be essential for optimizing irrigation scheduling and ensuring that crops receive the appropriate amount of water at the right time and for assessing extreme events.} For the purpose of this work, mainly focused on long-term assessment, planning, and decision-making, monthly data provide a broad overview of water availability, crop water requirements, and water balance of a region to identify trends in water availability and crop water use over a longer period. In addition, monthly data is easily available for any region and from different data sources;
potential evapotranspiration (PET): the definition of PET is the amount of evaporation that would occur if a sufficient water source were available, and the amount of water that would be evaporated and transpired if there were sufficient water available;

water balance: soil and water balance and water deficits are calculated based on the above data sets.

Selecting and calculating the indicators per watersheds
The calculation of composite indicators requires two sets of decisions: (i) selecting relevant criteria as inputs to each composite index; and (ii) specifying a weighting scheme by which criteria will be combined to calculate the composite. Each index represents a specific variable in the agriculture areas located within each watershed. The indexes were selected to evaluate the production trends and potential impacts of temperatures and PETs (and their increasing trends), rainfall, and water deficits.

For the comparison of the watersheds, five selected indicators constitute the base of the analysis to evaluate the productive situation according to the natural resource trends and production risks/pressure. The selected indicators and the corresponding weighting criteria are as follows:

- **relation of areas with declining productivity and with early signs of decline:** this indicator is a combination of the percentage of the areas with declining productivity and the percentage of the existence and relevance of croplands area per watershed. The higher the value – the greater the productive stresses;

- **annual precipitation trends:** the slope of the historical annual precipitation is considered as a ratio to measure rainfall variations (either increase or drop) on agriculture's exposure to climate variability and change. The lower the factor (negative slopes/trends), the higher the risks;

- **annual PET trends:** the slope of the historical annual potential evapotranspiration is considered as a ratio to measure the increase in crop water requirements. The higher the factor, the greater the risks;

- **climatic accumulative deficits and water deficit indicator:** these ratios indicate the magnitude of and potential risks related to a combination and balance of temperature, PET increase, effective precipitation (runoff and deep percolation) and soil and crop water balances. The higher the factor, the greater the pressure on the agriculture areas.
Define weighting criteria for composite indicators

A weighting process is essential to have mindful results. It defines a scheme by which the indicators will be combined to calculate the composite indicator for comparison of the agricultural areas.

In the development of a multi-criteria framework, the process of assigning weights to different indicators is a critical step that requires careful consideration and justification. The weights reflect the relative importance or priority assigned to each indicator in the decision-making process.

While a comprehensive assessment may involve numerous criteria, some may not have been included for various reasons, including: data limitations (some indicators may not have been considered due to data unavailability, poor quality, or lack of relevant information); irrelevance (certain criteria may not align with the specific objectives of the study or are deemed irrelevant to the decision-making process); resource constraints (conducting assessments for an excessive number of criteria can be resource-intensive and time-consuming); duplication (certain criteria duplicate the information provided by others, their inclusion may not add significant value to the decision-making process, making them unnecessary); lack of consensus (some criteria may have been excluded if there was a lack of consensus among stakeholders or experts on their relevance or significance).

For these reasons, the indicators and the weighting criteria for the multi-criteria framework have to be carefully chosen to reflect the most critical aspects of the decision-making process while taking into account stakeholder input, data availability, policy alignment, and sustainability considerations. The aim is to ensure a robust, transparent, and effective decision-making process that aligns with the objectives of the assessment.

Specifying a weighting scheme by which criteria will be combined to compare the watershed criticality by the composite indicator can be accomplished by:

1. applying a principal component analysis;
2. can be subjectively determined; or
3. set to be equal.

In the case of Belize, we used the second alternative by specifying subjectively the weights.

Below is the weighting that has been applied to the identified composite indicator.

<table>
<thead>
<tr>
<th>Selected indicators</th>
<th>Weighting</th>
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<tr>
<td>Relation of areas with declining productivity and with early signs of decline</td>
<td>30%</td>
</tr>
<tr>
<td>Annual precipitation trends</td>
<td>20%</td>
</tr>
<tr>
<td>Annual PET trends</td>
<td>20%</td>
</tr>
<tr>
<td>Climatic accumulative deficits</td>
<td>15%</td>
</tr>
<tr>
<td>Water deficit indicator</td>
<td>15%</td>
</tr>
</tbody>
</table>

SOURCE: Authors’ own elaboration.
The selection of the indicators and the weighting were discussed with the counterparts’ officials, while testing different combinations to reach a consensus on the most important decision factors in watershed selection. Discussions involving representatives of national institutions, FAO, and the World Bank led to identifying the essential decision criteria.

Applying these indicators as well as the criteria to the list of the agriculture areas provides the composite indicators per watershed (Figure 2). The results show a complete prioritization and ranking of the watersheds according to the stress of climate trends and production responses.

Figure 2
Agriculture areas – composite indicators per watersheds

Based on the previous assessments and according to the historic climatic and natural resources, the most critical watersheds are Belize River, Rio Hondo, and New River Watersheds.
**DETAILED ANALYSIS OF PRIORITIZED WATERSHED**

Specific and detailed analyses were carried out to identify potential investments and the impacts of future climatic scenarios on the main crops for these three prioritized watersheds.

Therefore, we proceeded with creating a 1 km x 1 km (100 ha) grid, dividing watersheds and agriculture areas into operating frames (Figure 3). All the data and models can be downscaled automatically thanks to a specific script that will run via Earth Map/Google Earth Engine.

![Creating a grid per watersheds](image)

**Figure 3**

**Example of grid and frame analysis**

SOURCE: Authors' own elaboration based on Google Earth Pro, Imagery for Belize. Cited 25 January 2024. [https://www.google.com/earth/about/versions/download-thank-you/?usagewstats=1](https://www.google.com/earth/about/versions/download-thank-you/?usagewstats=1)

The development and execution of the methodology relied on a series of geospatial and analytical tools such as Google Earth, Google Earth Engine, QGIS, Earth Map, Acquastat, and Acquacrop.

These tools facilitated transposing data collected locally as well as from literature and remote sensing into interactive maps available on Google Earth; therefore, it was not required to open, operate or ultimately understand specific geographic information system (GIS) knowledge. All of the tools are freely available to download online.
### Table 2
**Description of the main tools used in methodology**

<table>
<thead>
<tr>
<th>Tool</th>
<th>Type</th>
<th>Main Function</th>
<th>Ownership</th>
<th>Open Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Earth Browser</td>
<td>Geospatial Data Browser</td>
<td>Visualize and correlate identified variables.</td>
<td>Google</td>
<td>Yes</td>
</tr>
<tr>
<td>Google Earth Engine</td>
<td>Remote Sensing Data Platform</td>
<td>Run the scripts designed to understand trends and projections of identified variables.</td>
<td>Google</td>
<td>Yes</td>
</tr>
<tr>
<td>Earth Map Browser</td>
<td>Remote Sensing Browser</td>
<td>Visualize and analyse remote sensing data from Google Earth Engine.</td>
<td>FAO</td>
<td>Yes</td>
</tr>
<tr>
<td>QGIS</td>
<td>Geographical Information System</td>
<td>Create maps and layers.</td>
<td>Open Source</td>
<td>Yes</td>
</tr>
<tr>
<td>Aquastat</td>
<td>FAO</td>
<td>Global information system on water resources and agricultural water management.</td>
<td>FAO</td>
<td>Yes</td>
</tr>
<tr>
<td>Aquacrop</td>
<td>FAO</td>
<td>Crop growth model to assess the yield response of crops to water and management on crop production.</td>
<td>FAO</td>
<td>Yes</td>
</tr>
</tbody>
</table>

SOURCE: Authors’ own elaboration.

The multidimensional approach allows the combination of different sources of information such as: i) the cropped areas; ii) the locations of farms (based on the Belize Agriculture Information Management System [BAIMS]) data and the data provided by sugar cane industry); iii) local climate data (temp, PET, Precip); iv) physical data (digital elevation models, surface water bodies, land cover); v) presence and type of infrastructures (roads, electricity, settlements) as well as land use data (cropping patterns). Therefore, the approach serves to obtain data at a different scale (e.g. watershed farm level) based on the specific context of each priority area (Figure 8).

Figure 4
**Possible detailing of the layers**

SOURCE: Authors’ own elaboration based on Google Earth Imagery and data (sugar cane) provided by the Belize sugar cane association.
This level of detail and the data gathered from the field demonstrate the relevance of such impacts on agriculture and identify the areas where specific investments (e.g. I&D) are needed. Furthermore, the methodology includes climate change projections and scenarios, and facilitates the forecasting of water needs at grid level.

The datasets, shape-files, and maps created\(^4\) include 1 square km resolution databases per watershed containing the data listed in Table 3.

**Table 3**
Datasets and map generated by watershed

<table>
<thead>
<tr>
<th>Dataset / Maps</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producers/Location of farms</td>
<td>BAIMS databases. Belize Agriculture Information Management System (BAIMS) is a web-based application that serves as a central repository for all agriculture data.(^4)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), based on a 1981-2020 quasi-global rainfall dataset. CHIRPS incorporates 5 km resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.</td>
</tr>
<tr>
<td>Max and Min Temperature</td>
<td>ERA 5 The European Centre for Medium-Range Weather Forecasts (1981–2020) Monthly aggregates. The pixel size is 0.25 (approx. 28 km at the equator). Period of observations: 1979 to near-present (4-month lag time for processing). Monthly aggregates have been calculated based on the ERA5 hourly values of each parameter; Unit = °C. <a href="https://ecmwf.int/">https://ecmwf.int/</a></td>
</tr>
<tr>
<td>Potential evapotranspiration</td>
<td>M–D16A2 - MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500 m SIN Grid Potential evapotranspiration or PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration, assuming no control of water supply. PET is defined as the amount of evaporation that would occur if a sufficient water source were available. Actual evapotranspiration or AET is the quantity of water removed from a surface due to the processes of evaporation and transpiration. %</td>
</tr>
<tr>
<td>Exceeding precipitation</td>
<td>Own calculations based on water balance, considering actual precipitations, run-off, percolation, effective precipitation. It is the total monthly rainfall that exceeds evapotranspiration of the reference crop and/or specific crops.</td>
</tr>
<tr>
<td>Drainage prone areas</td>
<td>Own calculations based on a combination of exceeding precipitation, slopes (flat areas), and soils with very slow infiltration.</td>
</tr>
<tr>
<td>Water Deficits Indicators</td>
<td>Own calculations based on water balance, water deficits, and soil and crop water balance. It is a ratio to measure the crop water deficits during dry periods for the reference and/or specific crops.</td>
</tr>
<tr>
<td>Impacts on production</td>
<td>Own calculations based on actual crop evapotranspiration, potential crop evapotranspiration and yield responses to water stress.</td>
</tr>
</tbody>
</table>

\(^4\) Please refer to Annex 2 for the map samples for the three priority watersheds.

**SOURCE:** Authors’ own elaboration.
Identification and characteristics of potential infrastructures

Climate models consistently project an increase in temperatures for the priority watersheds for all seasons in the future (2060–2069) compared to the present. Furthermore, rainfall is expected to decrease and become more variable, leading to intense rains and flooding while drought conditions will worsen.

Considering that these changes in temperature and rainfall will have significant impacts, investments in I&D and the uptake best fit climate-smart agriculture (CSA) technologies and practices could be a potential and effective measure to:

i. increase climate resilience of Belizean agriculture;
ii. enhance access to water in agriculture with a vision of optimizing water productivity, avoid additional groundwater extraction and contribute to enhanced water resource management for agriculture; and
iii. create conditions for crop diversification for introducing higher value-added products and/or increased land use intensity (such as double cropping, intercropping, high yield varieties, year-round production, etc.).

For the analysis and identification of potential investment alternatives and areas, we assessed alternative investments from three different sources of water:

- **surface water sources**: considering head works/diversion structures and deviations from permanent streams, branches, and rivers. As alternatives for intakes and conveying water to each area/cell, we evaluated two alternatives:
  - Alternative 1: pumping systems from surface water resources
  - Alternative 2: gravity

- **water-harvesting** alternatives from non-permanent sources involves capturing and storing water from sources that are not available year-round, such as rainwater runoff, seasonal streams, and intermittent rivers. The logic behind water harvesting from non-permanent sources is to capture and store as much water as possible during the wet season, so that it can be used during the dry season when water is scarce. These investments reduce the adverse impacts of rainfall variability solutions allow farmers to grow high-value crops even during drought years, especially for rainfed small farmers severely affected by droughts periods.

The analyses were carried out by defining specifics indicators to identify suitable locations for: i) water diversion from the hydrological network; and ii) water harvesting catchments, by using the AGRI World Sources platform, developed by the International Center for Tropical Agriculture (CIAT) and FAO:

- Alternative 3: water harvesting
groundwater: underground water resources are considered extensive, especially in the northern provinces. In the Ministry of Agriculture, the Irrigation Unit promotes and encourages the use of irrigation systems and does not condone underground water abstraction, a practice widely used by farmers. Nonetheless, there is no assessment of the underground water resources before installing ground water irrigation systems, therefore the knowledge of groundwater resources and quality is limited (BEST, 2008; BEST, 2009). Without adequate information about the characteristics of an aquifer, such as its recharge rate, storage capacity, and water quality, it is difficult to know how much water can be withdrawn without depleting the resource. Furthermore, the lack of regular monitoring of groundwater levels and quality is essential to track changes in the aquifer and to ensure that withdrawals are sustainable. In sum, exploiting groundwater resources without adequate information and sustainability assurance can lead to various negative impacts such as depletion, contamination, and other environmental and social consequences. Therefore, it is crucial to gather accurate information, regularly monitor the resource, and implement effective governance and regulatory systems to manage groundwater resources sustainably. Consequently, when applying the precautionary approach and a conservative profile, the groundwater resources were not included in the analysis.

Technical analysis of investment alternatives
The methodology combines advanced remote sensing data with advanced GIS tools and ground-truthing.

The algorithms developed run automatically at the 1 km2 grid cells providing all the data at the local level expressing the reality of that specific area, the costs of the investments, and the corresponding benefits and impacts for each alternative can be then calculated separately.

Alternative 1: pumping systems from permanent surface water sources: this alternative looked at the investments and operational costs of pressurized systems. It considers:

- investments costs: i) the cost of head work in addition to pumping station; ii) the pipe diameter and optimal/minimum length from the potential intake to the centre of the cell; iii) stand and distribution pipes; and iv) filtration system. Costs include associated fittings;
- operational costs: energy costs to pump the water from the intake elevation to the elevation of the cell +35 m of additional pressure for on-farm irrigation equipment. It considers USD 0.179/KWh for businesses, including all components of the electricity bill, such as the cost of power, distribution, and taxes.

5 The platform is accessible at https://agri-worldsources.com/login
Figure 5
Alternative 1 – Pumping investment costs
**Alternative 2**: gravity systems: this alternative looks at the investments and operational costs for conveying the water by gravity from the potential intakes to each cell. It considers:

- Investments costs: i) cost of head work; ii) the pipe diameter (to conduct the water by gravity), and required length based on the average slope of the stream/river and the surrounding area from the potential intake to the centre of the cell; and (iii) distribution pipes within the cell;
- operational costs: fixed operational costs depending on the length of the pipes.

![Alternative 2 Investment (USD/ha)](Image)

**Figure 7**

**Alternative 2 - Gravity system investment costs**

SOURCE: Authors’ own elaboration based on Google Earth Pro, Imagery for Belize. Cited 25 January 2024. [https://www.google.com/earth/about/versions/download-thank-you/?usagestats=1](https://www.google.com/earth/about/versions/download-thank-you/?usagestats=1)
Methodology

Alternative 2: Gravity Systems: this alternative looked at the investments and operational costs for conveying the water by gravity from the potential intakes to each cell. It considers:

- **Investment costs:** i) cost of intake; ii) the pipe diameter and required length based on the average slope of the stream/river and the surrounding area from the potential intake to the centre of the cell; and (iii) distribution pipes within the cell.;

- **Operational costs:** fixed operational costs depending on the length of the canal/pipes.

Figure 11. Alternative 2 – Gravity system Investment Costs

SOURCE: Authors.

Figure 12. Alternative 2 – Gravity system Operational Costs

SOURCE: Authors.

Alternative 3: Water harvesting alternatives: this alternative looked at the investments and operational costs for conveying the water by gravity from the potential intakes to each cell. It considers:

- **Investment costs:** i) upstream works, diversion, if any, from the water sources to the catchment/reservoir based on the slope of the surrounding area; ii) earthworks for the pond/reservoir; iii) impoundment area lining and complementary works; and iv) distribution pipes to the parcels;

- **Operational costs:** fixed operational costs depending on the slope of the area.

The AGRI World Sources webtool supports identifying potentially suitable sites for implementing intakes, catchments, and storage volume during the rainy season and maps the best routes for installing water pipes from the identified water source and the irrigation system/scope area.

The potentially suitable location for both solutions: i) intakes: potential water sources in rivers and streams with enough base flow and from where it is easy to convey water by gravity to the irrigation systems; and ii) water harvesting and catchments: identification of suitable sites for the implementation of catchments, water accumulation, and storage during the rainy season.

The locations of i) the potential water diversions; and ii) the catchments area and water harvesting potential are detailed in the maps in Figure 9.
Groundwater sources

Although the main source of fresh water in rural areas is predominantly groundwater, especially in the northern provinces, the information on groundwater resources and quality is limited.

There is no known assessment of the sustainable recharge rates, water depths, and hydrogeological characteristics of the aquifers that allows for groundwater analysis as a potential investment alternative.

It is crucial to gather accurate information, regularly monitor the resource, and implement effective governance and regulatory systems to manage groundwater resources sustainably when applying a conservative approach. The analysis did not consider groundwater resources as an alternative for expanding available water resources.
INTRODUCTION AND APPROACH
Changes in the climate in Belize are currently affecting the agriculture sector, and variability of yields and harvests for rainfed agriculture is already suffering from changes in timing and amounts of rainfall, while a perturbation of the agricultural calendar is widespread. In addition, intense rainfalls are causing soil drainage and erosion problems, and warmer temperatures are increasing the incidence of yield-reducing weeds, pests, and diseases. It is very likely that future changes in the climate will exacerbate these conditions.

Therefore, in the agriculture sector Belize expects a projected loss of production within the range of 10 percent to 20 percent, which could lead to million dollars in lost revenue by the year 2100 (Ramirez et al., 2013; CCCC, 2009).

Yields of the major crops, namely sugarcane, rainfed bananas, citrus, and red kidney beans, are all expected to decrease. These decreases in crop yields are caused by an increase in air temperature accompanied by higher evaporation rates, variable rainfall and an increase or decrease in rainfall depending on the location.

A comparison in crop yield simulations for a historical (1981–2019) period to the future (2060–2069) expected climate scenario (Figure 10) was made for the main crops cultivated in the northern area of the country.
Figure 10
Temperatures and precipitation projections at 2060


The assessments developed using the FAO Aquacrop model for sugar cane and maize are detailed in Figure 11.

**Figure 11**
Sugar cane yields – crops behaviour for the historical period (1981–2019) vs project 2060

SOURCE: Authors using Aquacrop.

The FAO Aquacrop model’s assessments for sugar cane and maize shows that:
- sugar cane yield is expected to decrease by 17 percent by 2060 (from currently 43.4 to 36.1 t/ha), which is 51 percent of the potential yield for sugar cane; and
- under the same conditions and crop calendar, maize production would not be viable in the future without irrigation.

**Table 4**
Sugar cane and maize yields under different scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Climate (1981 – 2019)</th>
<th>CC 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average yield (ton/ha)</td>
<td>Dry Yld (ton/ha)</td>
</tr>
<tr>
<td>Sugar Cane</td>
<td>Irrigated (*)</td>
<td>70.1</td>
</tr>
<tr>
<td></td>
<td>Rainfed</td>
<td>43.4</td>
</tr>
<tr>
<td>Maize</td>
<td>Irrigated (*)</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Rainfed</td>
<td>3.3</td>
</tr>
</tbody>
</table>

(*) with water stress management
(**) kg yield per m² water evapotranspired

SOURCE: Authors’ own elaboration.
A similar analysis was developed using the FAO Cropwat model for cabbage and onion using the following algorithm:

\[
\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_a}{ET_m}\right)
\]

where

\(Y_a\) = actual yield (corresponding to \(ET_a\)) [kg/ha]
\(Y_m\) = maximum theoretical yield (corresponding to \(ET_m\)) [kg/ha]
\( ET_a\) = actual crop evapotranspiration
\( ET_m\) = potential crop evapotranspiration
\( K_y\) = yield response factor to water stress, which comes from the Crop Library.

\( Y_a/Y_m\) is the relative yield fraction. Solving for \( Y_a/Y_m\):

\[
\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_a}{ET_m}\right)
\]

where

\(Y_a\) = actual yield (corresponding to \(ET_a\)) [kg/ha]
\(Y_m\) = maximum theoretical yield (corresponding to \(ET_m\)) [kg/ha]
\( ET_a\) = actual crop evapotranspiration
\( ET_m\) = potential crop evapotranspiration
\( K_y\) = yield response factor to water stress, which comes from the Crop Library.

\( Y_a/Y_m\) is the relative yield fraction. Solving for \( Y_a/Y_m\):

In both cases, yields are expected to decrease by 44.3 and 47.5 percent, respectively (see Table 3). Thus, the economic effects of climate variability and future scenarios are expected to affect the sustainability of agricultural production noticeably.

**Table 5**

**Cabbage and onion yield under different scenarios**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Scenario</th>
<th>Climate (1981 - 2019)</th>
<th>CC 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average yield (ton/ha)</td>
<td>% of variation</td>
</tr>
<tr>
<td>Cabagge</td>
<td>Irrigated (*)</td>
<td>29.0</td>
<td>+21.7</td>
</tr>
<tr>
<td></td>
<td>Rainfed</td>
<td>23.8</td>
<td>--</td>
</tr>
<tr>
<td>Onion</td>
<td>Irrigated (*)</td>
<td>20.6</td>
<td>+27.0</td>
</tr>
<tr>
<td></td>
<td>Rainfed</td>
<td>16.2</td>
<td>--</td>
</tr>
</tbody>
</table>

**SOURCE:** Authors’ own elaboration.
The economic analysis focused on the three prioritized agriculture watersheds located in the central and northern part of the country, namely: the Belize River, Rio Hondo, New River. Within these watersheds, the full spectrum of farmers operate (small, medium, and large farmers) with a focus on sugar, corn, beans, vegetables and tree crops, which are the most important non-irrigated crops in the country.

The economic analysis looked at the economic performance of key crops under three different surface water irrigation scenarios: pumping irrigation, gravity irrigation and water harvesting (either from rain or river stream diversion).

Benefits simulated from the investment in irrigation include: i) increased crop yields and productivity due enhanced agriculture practices based on CSA packages developed by CIAT and the World Bank (World Bank, 2020), water availability, and cropping intensity use (more cropping cycles per year); ii) an increased proportion of marketed farm produce; iii) improved quality of products, thus attracting higher prices as a result of the demand by processors for more reliable inputs/outputs.

The main objective of the analysis is to examine the economic viability of the main crops under the technologies proposed. It assesses their potential for increased profitability as a result of proposed interventions and whether:

- technologies would offer sufficient financial incentives to attract participants amongst target group; and
- cash incomes generated by these technologies would be adequate for the farmers and rural entrepreneurs to repay their additional investments.

The analysis compares the situation without intervention in a likely scenario which includes technologies adoption. Without a new technologies project, it is expected that farmers would continue with the existing low-input, low-output production systems, with a decreasing output due to land degradation and low resilience to extreme climatic events (droughts and floods). The results have been analysed and the benefits highlighted to provide guidance for future analysis and investments.

The most important cultivated crops included in the project areas include sugar, grains (corn and rice), tree crops (citrus and coconut), beans, and livestock and vegetable crops (cabbage, sweet peppers, tomatoes). Irrigation is not very common in Belize except in the case of banana farms and rice fields. There are some pivot irrigation systems in the country for the corn, beans, and soya areas.

Climate-smart agriculture represents an opportunity for Belize (World Bank, 2018) and overall, twenty-four representative agriculture CSA packages have been developed by CIAT in collaboration with the World Bank in the country. For the purpose of this analysis, and based on the prevalent crops grown in the focus watershed, four representative CSAs have been retained (Table 6) as the most likely to be adopted in the focus areas by farmers. However, these packages of possibilities available to farmers in Belize are not exhaustive.

---

6 Farmers with land plots between 0.5 and 20 acres, for example, would be considered small, and farmers with land plots above 20 acres would be considered medium and large.
Table 6
Representative CSA practices retained for the analysis

<table>
<thead>
<tr>
<th>Crop</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Water-efficient irrigation and planting varieties</td>
</tr>
<tr>
<td>Corn</td>
<td>Water-efficient irrigation and crop rotation</td>
</tr>
<tr>
<td>Beans</td>
<td>Water-efficient irrigation and crop rotation</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Water-efficient irrigation and crop rotation</td>
</tr>
</tbody>
</table>

SOURCE: Authors’ own elaboration.

The data of the analysis are based on three studies prepared by the World Bank and CIAT (World Bank, 2018; Ministry of Agriculture, 2019; Belize 2019 agriculture CENSUS) and field visits.

Financial prices are market-determined for crop production, while market prices are based on data obtained from field visits, discussions with officers in the concerned districts, and official statistics. Prices used in the analysis are in constant-dollars (2020). The agriculture sector is subsidized, but according to the review of agriculture sector support and taxation in Belize (IADB, 2017) the crops targeted by the analysis do not benefit from major distorting support.

Thus, there are no other major direct input or output subsidies affecting these representative cases, and tariffs were not taken into account partly due to the volatile nature of tariffs on some agricultural products. The estimated parameters include incremental annual revenues, net benefits/income, NPV of benefit flows (at a 12 percent annual discount rate); and the internal rate of return (IRR).

In general, the labour supply is not a major constraint to farm and non-farm activities development in the focus area, as there is sufficient local unskilled labour. The family labour available can amply meet the on-farm and off-farm requirements and the future increase in demand. The cost of daily farm labour is USD 12 based on the minimum salary scale at the time the study took place.

The analysis is based on a 1 km² cell equivalent to 100 hectares of available agriculture land. The total potential hectares designated for irrigation that would be considered feasible from an economic point of view depends on the technology proposed and the crops. The analysis simulates various technologies adoption.

While the crop budgets show increase in gross margins (revenues minus operating costs for each crop) with moving from rainfed to irrigated agriculture due to significant improvements in yields and income, the financial viability at the cell level depends on the investment costs for bringing the water, linked to the geographic location of the cell.

The investment costs for the selected technologies have been estimated and used as a basis for the calculation of financial returns. Total investment costs per hectare show a wide range from USD 2000 to over USD 10 000, while the operational costs from USD 100 to USD 1000. The on-farm equipment costs have been set at USD 2500/ha through the analysis keeping with national averages and neighbouring countries data.

The analysis uses a cash flow model over a 20-year period that includes all investment and operational costs for the three different proposed surface water resources-based irrigation alternatives, namely: surface water pumping...
irrigation, gravity irrigation, and irrigation from water harvesting reservoirs. Furthermore, it includes the incremental net revenues derived from the financial models based on the World Bank CIAT recent work on CSA potential for Belize and updated with current crop prices. The future scenario makes the assumption of no cropping pattern switches for land cultivated for sugar.

The economic cost has been calculated using a preliminary estimation of investment and operation and maintenance cost. Total investments have been estimated for each cell of 1 km2 as well as the recurrent cost for water use and on farm investments.

The overall economic cash flow and the corresponding economic IRR and NPV have been calculated by aggregating the net incremental benefits that are obtained by the beneficiaries as a result of additional production (yield and productivity increase) for each cell.

The economic analysis is based on direct costs and benefits. Social, institutional, and indirect benefits will not be taken into account. These include, for example, creation of employment, enhanced competition in input markets, enhanced national food security, import substitution, foreign currency earnings, and emergence of farmers’ organizations.

The results have been then classified into three categories:
- unsuitable for investments: IRR < 12 percent red-colour cells;
- suitable for investment with more analysis required: 12 percent<IRR<18 percent yellow cells;
- priority areas for investments: IRR>18 percent green cells.

Three irrigation alternatives are proposed and analysed from an economic point of view:
- pumping irrigation (Alt1 in the maps and tables);
- gravity irrigation (Alt2 in the maps and tables);
- water harvesting (Alt3 in the maps and tables).

Maps have been developed for each watershed and technology to visually reflect the results of the analysis, and are further discussed in detail for each of the focus watersheds.

However, it must be noted that data on water availability is a challenge and all suitable areas are subject to the review of actual water availability. Complete information related to water availability is still unavailable.
NEW RIVER WATERSHED

Over 76,000 hectares are classified as agriculture areas, predominantly for sugar production, as this watershed together with the Rio Hondo watershed form what is called the north sugar belt. The three irrigation alternatives have been tested for the crops mentioned above. The results in Table 7 indicate an area of close to 21,000 hectares economically viable for sugar under irrigation (IRR above 12 percent) equivalent to 27 percent of the agriculture area.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt1 IRR Sugar &lt;12</td>
<td>55,352</td>
<td>73%</td>
</tr>
<tr>
<td>Alt1 IRR Sugar 12 -18</td>
<td>20,877</td>
<td>27%</td>
</tr>
<tr>
<td>Alt1 IRR Sugar &gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Alt2 IRR Sugar &lt;12</td>
<td>69,911</td>
<td>92%</td>
</tr>
<tr>
<td>Alt2 IRR Sugar 12 -18</td>
<td>6,318</td>
<td>8%</td>
</tr>
<tr>
<td>Alt2 IRR Sugar &gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Alt3 IRR Sugar &lt;12</td>
<td>76,229</td>
<td>100%</td>
</tr>
<tr>
<td>Alt3 IRR Sugar 12 -18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Alt3 IRR Sugar &gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
</tbody>
</table>

Total agriculture area 76,229

SOURCE: Authors’ own elaboration.

The irrigation alternative most suitable for sugar is pumping irrigation, while gravity irrigation has only limited profitability in very specific areas (see picture in Figure 12) and is limited to around 6000 hectares equivalent to 8 percent of the agriculture area. The high investment and running costs of the water-harvesting alternative makes it unprofitable for sugar production.
Sustainable agriculture development resilient to climate change through irrigation and drainage planning

Table 7. IRR results by technology for sugar crop

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt1 IRR Sugar</td>
<td>&lt;12</td>
<td>55.352</td>
</tr>
<tr>
<td>12 -18</td>
<td>20.877</td>
<td>27%</td>
</tr>
<tr>
<td>&gt;18 -</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Alt2 IRR Sugar</td>
<td>&lt;12</td>
<td>69.911</td>
</tr>
<tr>
<td>12 -18</td>
<td>6.318</td>
<td>8%</td>
</tr>
<tr>
<td>&gt;18 -</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Alt3 IRR Sugar</td>
<td>&lt;12</td>
<td>76.229</td>
</tr>
<tr>
<td>12 -18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18 -</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Total agriculture area</td>
<td>76.229</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: Authors.

The irrigation alternative most suitable for sugar is pumping irrigation, while gravity irrigation has only limited profitability in very specific areas (see picture in Figure 14) and is limited to around 6000 hectares equivalent to 8 percent of the agriculture area. The high investment and running costs of the water-harvesting alternative makes it unprofitable for sugar production.

Figure 14. New River – IRR results by technology for sugar crop


In addition to identifying the above area where irrigation investments are feasible, the methodology also provides information related to areas and producers with limited viability for rainfed sugar cane production under future projected scenarios (see map in Figure 13).

For the New River watershed, the results give an area of close to 21000 hectares economically viable for sugar under irrigation (IRR above 12 percent – green zone), equivalent to 27 percent of the agriculture area.

For the producers located in the western (yellow area), where investments in irrigation are not economically viable for sugar cane, it is necessary to identify and put in place policies and investments to create conditions for crop diversification. It implies introducing higher value-added products and increased land use intensity (e.g. double cropping, intercropping, high-yield varieties, year-round production, etc.) and water-harvesting investments.

Figure 13
Map of areas and producers with limited viability for rainfed sugar cane production under future projected scenarios

**RIO HONDO WATERSHED**

Over 64,000 hectares are classified agriculture areas – crops predominantly being sugar, corn, beans and some tree crops. This watershed along with the New River watershed form what is called the north sugar belt. The three alternatives have been tested for both sugar and corn/beans rotation.

**Table 8**  
Rio-Hondo-IRR results by technology for sugar cane

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alt1 IRR Sugar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>41,785</td>
<td>65%</td>
</tr>
<tr>
<td>12-18</td>
<td>22,234</td>
<td>35%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>62</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Alt2 IRR Sugar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>52,559</td>
<td>82%</td>
</tr>
<tr>
<td>12-18</td>
<td>11,521</td>
<td>18%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Alt3 IRR Sugar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>64,080</td>
<td>100%</td>
</tr>
<tr>
<td>12-18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Total agriculture area** 64,080

SOURCE: Authors' own elaboration.

The results give an area of around 22,000 hectares economically viable (IRR above 12 percent) for sugar under pumping irrigation, equivalent to 35 percent of the agriculture area, while the area economically viable using gravity irrigation exceeds 11,000, equivalent to around 18 percent of the agriculture area. The third option, water harvesting is not an efficient option for sugar in the watershed.
The three alternatives tested for the corn/beans rotation are summarized in Table 9. The suitable areas increase under pumping irrigation, while they decrease under gravity irrigation. The third alternative for water harvesting is not economical for the corn/beans rotation in the watershed.

Table 9
Rio Hondo-IRR results by technology for corn/beans rotation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt1 IRR Corn/Beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>39,634</td>
<td>62%</td>
</tr>
<tr>
<td>12 -18</td>
<td>24,446</td>
<td>38%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Alt2 IRR Corn/Beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>55,949</td>
<td>87%</td>
</tr>
<tr>
<td>12 -18</td>
<td>8,131</td>
<td>13%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Alt3 IRR Corn/Beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>64,080</td>
<td>10%</td>
</tr>
<tr>
<td>12 -18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Total agriculture area</td>
<td>64,080</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: Authors’ own elaboration.
Over 24,000 hectares are economically viable using pumping irrigation while about 8,000 hectares are viable using gravity irrigation. Figure 14 provides a graphic illustration of the economic results. The third option, water harvesting, is not an economical option for sugar in the watershed.

**BELIZE RIVER WATERSHED**

The Belize River is the largest and most diverse watershed of Belize. Over 131,000 hectares are classified as agricultural land, with a variety of crops including, corn, beans, vegetables and tree crops. This watershed includes a large swath of protected areas. The three irrigation alternatives have been tested for both vegetables and corn/beans rotation, which are the most interesting crops to cultivate under irrigation in the watershed.

### Figure 15

**New River – IRR results by technology for corn/beans crops rotation**

Table 10
Belize River–IRR results by technology for vegetable crops

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt1 IRR Vegetables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>12 - 18</td>
<td>660</td>
<td>1%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>130,920</td>
<td>99%</td>
</tr>
<tr>
<td>Alt2 IRR Vegetables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>12 - 18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>131,580</td>
<td>100%</td>
</tr>
<tr>
<td>Alt3 IRR Vegetables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>12 - 18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>131,580</td>
<td>0%</td>
</tr>
</tbody>
</table>

Total agriculture area 131,580

SOURCE: Authors' own elaboration.

The prospects for vegetables are extremely promising and the total area would be suitable under the three different options proposed. The high-end price of the vegetables (tomatoes, onions and other) simulated under this scenario make the irrigation always viable with IRR values well above 18 percent. Figure 16 provides a graphic illustration of the economic results. The results, especially for the water harvesting solution, confirm the findings of neighbouring countries such as Honduras.
The prospects for vegetables are extremely promising and the entire area would be suitable under the three different options proposed. The high-end price of the vegetables (tomatoes, onions and others) simulated under this scenario make the irrigation always viable with IRR values well above 18 percent. Figure 17 provides a graphic illustration of the economic results. The results, especially for the water harvesting solution, confirm the findings of neighbouring countries such as Honduras.

When the irrigation technologies are tested against the corn/beans crop rotation, the results are still very promising.

### Table 11
Belize River-IRR results by technology for corn/beans crop rotation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hectares</th>
<th>% Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alt1 IRR Corn/Beans</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>27,644</td>
<td>21%</td>
</tr>
<tr>
<td>12 -18</td>
<td>22,763</td>
<td>17%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>81,173</td>
<td>62%</td>
</tr>
<tr>
<td><strong>Alt2 IRR Corn/Beans</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>21,561</td>
<td>16%</td>
</tr>
<tr>
<td>12 -18</td>
<td>37,651</td>
<td>29%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>72,368</td>
<td>55%</td>
</tr>
<tr>
<td><strong>Alt3 IRR Corn/Beans</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;12</td>
<td>131,580</td>
<td>100%</td>
</tr>
<tr>
<td>12 -18</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;18</td>
<td>-</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Total agriculture area** 131,580

**SOURCE:** Authors using Aquacrop.
Close to 80 percent of the total agriculture area is economically viable for pumping irrigation. More precisely 62 percent, which is equivalent to over 81,000 hectares, have an IRR of above 18 percent. The share of land economically suitable for gravity irrigation is higher (84 percent, 110,000 ha), but the share of land exceeding the 18 percent IRR is slightly lower: 55 percent. As expected, the water-harvesting option, is not a viable option under the corn/beans rotation.

**Figure 17**
Belize River – IRR results by technology for corn/beans rotation

Conclusion and recommendations

Belize agriculture provides a livelihood for thousands of farmers and is a major contributor to the national gross domestic product, nevertheless, it is threatened by climate change. Evidence has shown that the impact of the changing climate variables (such as temperatures and precipitation) have been growing stronger in recent years, due to droughts that are impacting the sugar belt in the northern part of the country and flooding the coastal flat regions.

Planning for adaptation measures for the future of the sector will be key to supporting agriculture in an organic- and climate-resilient manner. In particular, water management related investments have been prioritized by the government in order to cope with climate change. Irrigation from surface water resources and drainage investments have the potential to contribute to Belize’s agricultural development goals by: i) sustainably increasing productivity, for example in the sugar belt; ii) enhancing resilience; and iii) allowing farmers to deliver fresh vegetables and fruits during the dry season (which precedes and overlaps with the relatively high demand generated by the high season of tourism).

Several reasons motivated the development of a framework to propose infrastructure investments in the water sector: i) the need to improve infrastructure planning and decision-making at the national and local levels; ii) the fact that the government frequently faces the challenges of assessing large numbers of projects and requests to allocate the financial and technical resources; iii) the need to address environmental and social factors in infrastructure development, often difficult to assess holistically and consequently to properly monetize them; and iv) the desire to balance analytical efficiency with policy and political responsiveness.

The methodology presented in this paper offers the possibility to: i) analyse current climate change trends and assess impacts of climate projections (e.g. A1, A2, B1 and B2) and their effects on agriculture production; and ii) estimate the investments required to bring the necessary supplemental water to keep the production at attractive economic levels. This innovative methodology is based on the combination of ground data (e.g. national statistic, national agrarian census, cadaster, interviews) with advance remote sensing and data processing tools such as FAO EarthMap, Collect Earth, Google Earth, Aquastat and Aquacrop.
The combined use of these different tools and applications allowed for mapping and quantifying the interaction between different dimensions/variables. The final step has been a preliminary economic analysis providing clear maps at watershed level, disaggregated at a 1 km² grid and focused on agriculture areas, of the expected IRRs according to the simulated investments, cropping patterns and irrigation technology proposed.

The analysis in this report focuses on the three watersheds: Belize River, Rio Hondo and New River that scored the highest in terms of priority. It demonstrates that it is possible to facilitate a meaningful prioritization framework to support investment decisions in the Belizean agriculture water sector crossing, climate technical and economic data. The methodology is flexible enough to shift crops or geographical focus, and frame the prioritization analysis and relevant investment considerations that could be translated into decision criteria accordingly. However, it is important to note that data on water availability represents a challenge, and all areas concerned are subject to a review of the actual water availability. At present, information related to water availability is still incomplete.
References


FAO. 2020. EarthMap – Belize, 2020. Cited 20 December 2023. https://earthmap.org/?layers=%7B%22lat%22%3A0%2C%22lng%22%3A0%7D%2C%22zoom%22%3A3%2C%22type%22%3A22%22%22roadmap%22%7D).


McSweeney, Carol. 2010. UNDP Climate Change Country Profiles — Improving the Accessibility of Observed and Projected Climate Information for Studies of Climate Change in Developing Countries.


The main focus of this report is on climate-resilient irrigation and drainage (I&D) investments, with the aim to improve agricultural production and productivity in Belize. To achieve this task, FAO has developed an innovative methodology based on the preparation of a multi-criteria framework. The objective of this methodology is to identify I&D investments to help policymakers and investors target investment resources. Aligned with Belize's climate resilience commitments, our findings present essential insights that pave the way for stakeholders to develop effective investment strategies to support the agriculture sector. In collaboration with Belize, FAO’s ultimate goal is to promote sustainable and resilient food systems.

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