Sustainable Development Plan for the CMCC Region

May 2020

INTERIM REPORT on Spatial Data, Models and Scenarios

This report (Deliverable 3) provides an update between August 2019 and April 2020 on spatial data analysis, scenarios, the modeling framework for trade-off analysis. This report builds on the data collection undertaken to complete the Sustainable Development Planning Consultancy, as described in the prior interim report of Jan 2020. After having completed the stakeholder consultations and data collection, baseline models and full development scenarios were developed, along with economic models of selected ecosystem services, to inform the selection of development options. In addition to the ecosystem service tools and valuation of services, stakeholder input was used to validate the baseline models, the results of the full development scenarios, and the selection of initial development options. Initial recommendations on development options were presented to the SDP Steering Committee in April 2020 to evaluate the viability of the findings and the underlying models.

Contents

Contents 1

1. Introduction 3

2. Overview of Assessment Approach 5

3. Identifying priority ecosystem services and benefits 6

Stakeholder consultation workshop 7

4. Identifying development pressures 9

4.1. Full development scenarios 9

5. Methods: Ecosystem Services Modelling 11

5.1. Water flow & availability 11

5.2. Water quality 12

5.3. Carbon 13

5.4. Beneficiaries & cumulative impacts 13

6. Methods: Economic valuation 15

6.1. Tourism 15

6.2. Carbon 16

6.3. Timber 16

6.4. Agriculture 17

6.5. Hydropower 17

6.6. Water quantity and quality 18

7. Results **18**

7.1. Current ecosystem services from the CMCC 18

7.2. Economic benefits 22

7.3. Risks and trade-offs of full development in the region 22

8. Potential development activities **24**

8.1. Zoning recommendations 24

8.2. Development options and scenarios 25

9. Other considerations for the SDP **26**

10. Path forward: next steps **27**

11. References **27**

Sustainable Development Plan for the CMCC Region

INTERIM REPORT ON SPATIAL DATA, MODELS AND SCENARIOS

1. Introduction

The Natural Capital Project at Stanford University (NatCap), in partnership with the Inter-American Development Bank (IADB), the University of Belize Environmental Research Institute (UB-ERI), the Economic Development Council (EDC) and the Government of Belize have advanced all the necessary activities to develop the Sustainable Development Plan (SDP) for the Chiquibul-Mountain Pine Ridge-Caracol Complex (CMCC; Figure 1). The goal is to integrate state-of-the-art ecosystem services mapping and analysis with stakeholder interests, values, and knowledge into an ecosystem-based SDP that maintains the long-term economic prosperity of the region and balances resource use with environmental protection and local livelihoods. Developing a Sustainable Development Plan for this region serves as an important model for other regions in Belize because of its unique biological and cultural value, coupled by the fact that it is the largest block of contiguous tropical broadleaf forest in Central America with areas of socio-cultural significance like the Caracol Archaeological Reserve.

The challenge set forth is finding alternatives to address limitations that the only access roads from the main George Price Highway for economic activity and tourism are the Georgeville and Santa Elena Junction roads, which join together just before entering the Mountain Pine Ridge Forest Reserve to form the A10/Chiquibul road. Pending plans to improve this road network from Georgeville to Caracol have raised concerns that unplanned development and improved access could lead to degradation of both natural and cultural assets.

If the road is improved without attention to proactive planning, there is a danger that the primary potential values of the area – namely its Mayan cultural heritage, water supply for downstream communities, eco-tourism, energy production potential, and other regulating and provisioning ecosystem services – will be threatened or compromised before their full value can be realized.

Today, the primary economic activities within the CMCC include tourism, timber extraction, mining, and power generation at three sites along the Macal River. Historically, timber extraction served as the primary economic driver for creation and maintenance of the Forest Reserves, but there is a growing industry around adventure tourism. Currently an average of around 10,000 visitors/year visit the Caracol Archeological Reserve – about 1/8 of the total visitations to neighboring San Ignacio Town. Improvements to the Caracol road are expected to increase visitors to the region, which in turn can impact water supplies, waste disposal, and security, while potentially bringing jobs and economic growth to the area.

This report (Deliverable 3) details the results of the spatial modeling and analysis of ecosystem services and their values, both in the current situation (baseline) as well as under different scenarios of development pressure. Sensitivity analysis, calibration and validation of the ecosystem service models were completed to develop biophysical and valuation models of the impacts of current and future development scenarios. This includes summarizing the trade-offs in biophysical and/or economic metrics, depending on the service. Stakeholder input was incorporated throughout this process, and the results laid out in this report provide the basis for recommendations of specific development options to be considered for the final trade-off analysis and development of the SDP.

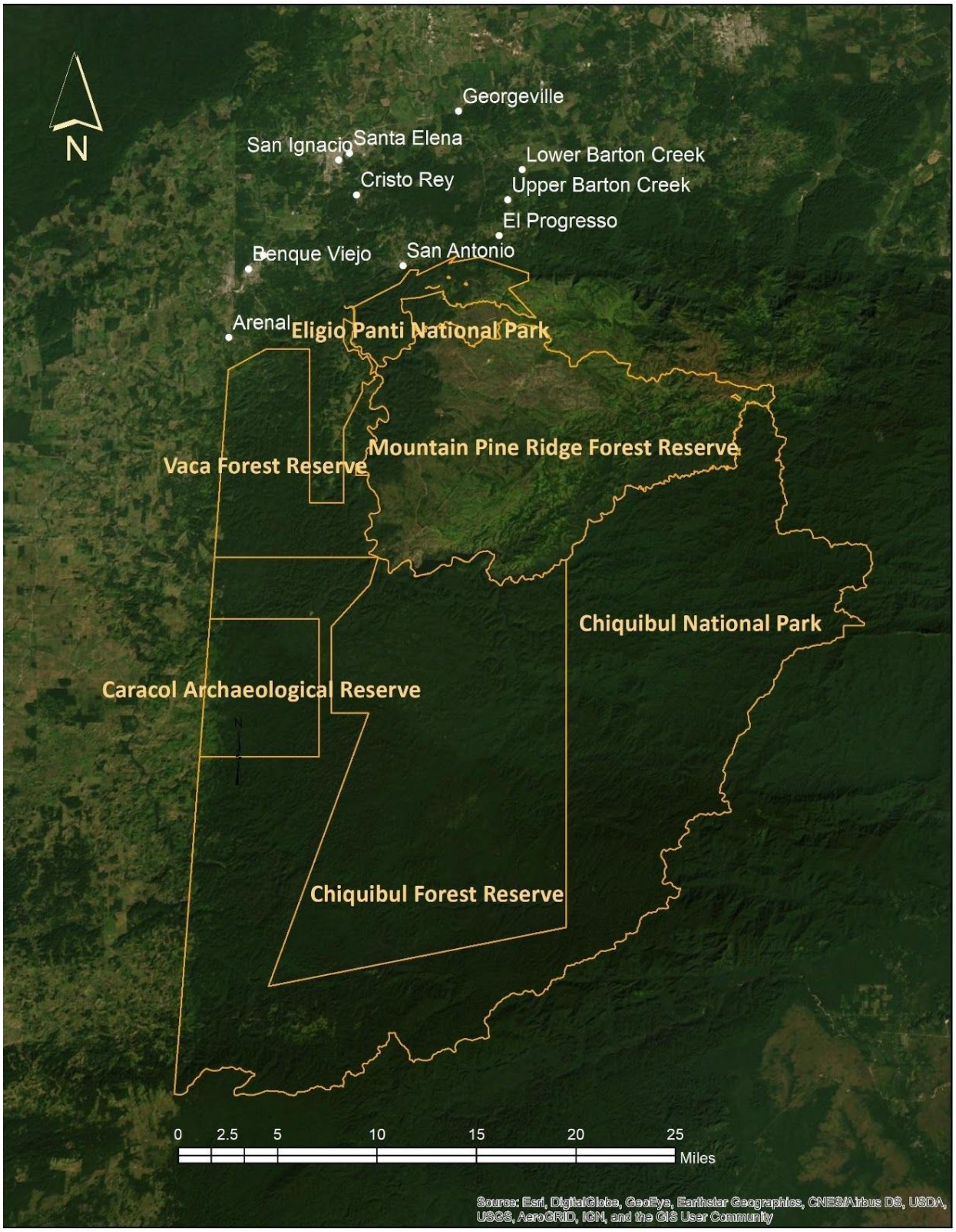


Figure 1. Map of CMCC region and surrounding communities. The Chiquibul-Mountain Pine Ridge-Caracol Complex includes four protected areas under different designations and management regimes (Chiquibul Forest Reserve, Chiquibul National Park, Mountain Pine Ridge Forest Reserve (MPR), and Caracol Archaeological Reserve); there are several other protected areas and communities buffering this area. Land management and drivers in these buffer areas will have important consequences for the delivery of ecosystem services from the CMCC region.

2. Overview of Assessment Approach

The development of an SDP for the CMCC region, one that is informed by an assessment of ecosystem services, development options, and trade-offs, encompasses the following steps:

1. Identify key ecosystem services and benefits
2. Identify development pressures
3. Ecosystem service modeling
    - Develop and calibrate baseline models
    - Analyze scenarios to identify hotspots of potential impact
4. Economic modeling
5. Identify sustainable development options
6. Analyze trade-offs
7. Governance
8. Develop SDP

This report details the results of steps 1 through 5.

Typically, an assessment of ecosystem services includes developing biophysical models to simulate each service under current conditions, validating the models against observed data (where possible), simulating the change in each service that could be expected under different development scenarios, linking these changes to impacts on the beneficiaries of these services in specific locations, and then valuing (where feasible) the changes in each service considering the social preferences of the beneficiaries.

Because of the complexity of connections between land management, development options, community benefits, and socio-economic values, our assessment of trade-offs for different development options incorporates qualitative information, quantitative information on biophysical changes, and quantitative information on economic values. First, information gleaned from stakeholder engagement process is systematized into ecosystem services objectives (see Section 3) and other development objectives (see Section 9). From the list of ecosystem services, available data and potential modeling approaches were evaluated to determine if impacts of development scenarios may be reliably quantified. If not, the impacts were treated qualitatively, based on input from the Government of Belize, other stakeholders, and literature review of studies from similar areas. If changes can be reliably modeled, then quantitative changes are reported. For each of those services, available data were evaluated to determine if the changes in service provision can be robustly valued in economic terms. If so, then economic impacts are reported. In this way, the assessment of trade-offs incorporates analyses in qualitative, quantitative (biophysical) and in socio-economic terms, depending on the availability of data (Figure 2).

As with any landscape-scale study of this kind, some data gaps are likely to remain that will require generalization or simplification. Every effort has been made to use the best-available data for assessing each ecosystem service and its value, and for ensuring that any recommendations made do not overreach the information base on which the analyses are founded.

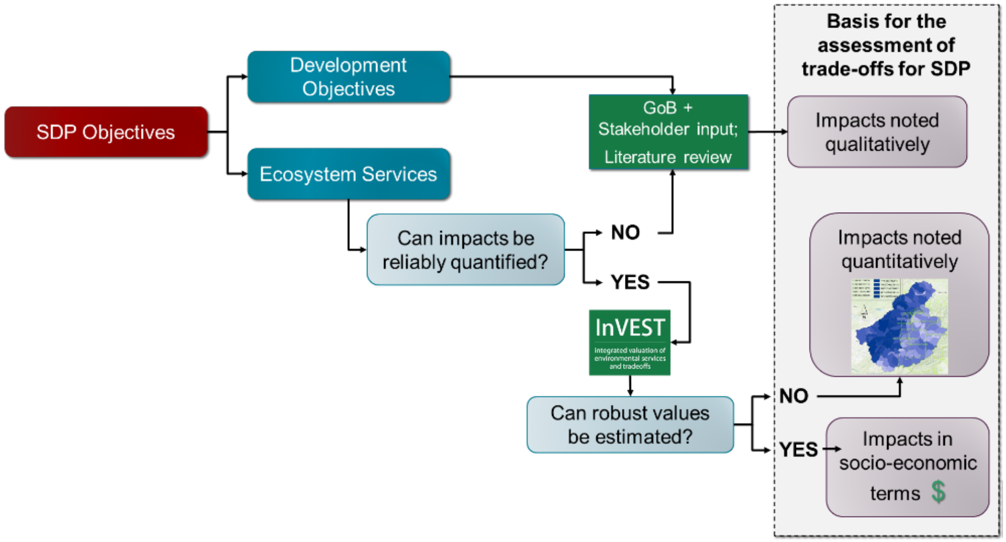


Figure 2. Decision process for developing information for trade-off analysis.

3. Identifying priority ecosystem services and benefits

The results from the first stakeholder workshop laid out an initial list of ecosystem services that were included in the Interim report on Data Collection and Ecosystem Services Mapping. Based on the second stakeholder workshop held in August 2019, we have identified a list of ecosystem services that will be considered in the SDP, the type of benefits received, and by whom (Table 1). These fall into the following categories: water flow and availability, water purification, tourism & recreation, carbon storage, timber production, and other productive activities. These services can be thought of as the objectives for which the landscape might be managed – that is, the quantitative attributes that stakeholders want to maintain into the future.

Through the workshop consultation we were able to further analyze development pressures and threats, mapped natural, cultural and economic assets and opportunities, and developed the most comprehensive spatial inventory to date for the area.

Table 1. Summary of ecosystem services from the CMCC, the type of benefit received, and output metrics used to quantify the impacts of different development scenarios on these services.

Ecosystem service	Benefit stream (value)	End point reported (change from baseline)	
		Biophysical	**Socio-economic**
Water flow and availability	Drinking water supplies for communities, resorts, archaeological sites, etc.	Baseflow in watersheds providing drinking water to communities and resorts in the CMCC area	[Avoided cost of obtaining alternate supplies*]
	Tourism/swimming, tubing, rafting sites	Baseflow in watersheds providing flow to recreation & tourism sites	--
	Hydroelectric energy generation	Baseflow at Vaca, Mollejon and Chalillo dams Energy generated	Price of energy generated
Water quality	Clean drinking water supplies for communities	Sediment and nutrient loads in watersheds providing drinking water to communities and resorts in the CMCC area	--
	Clean water for tourist, swimming, and recreation sites	Sediment and nutrient loads at recreation sites	--
Tourism & recreation	Income to private investors, resorts, tourism operators; Job creation and economic growth for communities; Revenues for the GoB	Footprint of area zoned for tourism development Number of accommodations Average occupancy rate Expected number of visitors Annual water demand	Tourism revenue
Timber	Timber concessionaires	Timber harvested annually	Revenue from timber sales
Carbon	Carbon sequestration for climate change mitigation	Total carbon stock	Value of carbon stock
Agricultural production	Crop production and/or revenue	Area of land in crop production	Revenue from crop production
Ecosystem health and habitat quality	Maintenance of healthy ecosystems for biodiversity, tourism value, and general ecosystem services	Footprint of natural habitats impacted by developments	--
Other productive activities currently in the region (not quantified or valued): Harvesting of medicinal plants and xate, mining, and military training camps.			

* While early scoping efforts were not promising, the modeling team is currently looking again to see if any data are available to enable this valuation.

4. Identifying development pressures

The second stage of our assessment involved identifying development pressures that are likely to impact how the CMCC region looks in the future. This exercise is important to understand which areas are under the most pressure, and therefore most likely to be impacted by development in the absence of a proactive, sustainable plan, and those that are most sensitive to development.

4.1. Full development scenarios

During the second stakeholder workshop in September 2019, participants were asked to envision the best and worst possible futures for the region. Stakeholders drew their visions from the future on maps, which contained information on the current land use and management (Figure 3), as well as the location of critical assets such as roads, water features, and water sources for communities. The information on these maps was digitized through various methods, and combined with the current land cover map to create scenarios representing the most extensive possible development envisioned for 20 years in the future. These scenarios were used as input to the InVEST models, to understand where and how much services may change from the current conditions, if these developments were to occur.

The tourism expansion scenario includes all of the tourism and recreation sites identified by workshop participants, with a 500 meter buffer around them to indicate the potential expansion of facilities, which are treated as developed areas. Participants also expressed concern that without proactive development planning, there would likely be rampant land speculation along the improved road followed by continuous tourism-related developments. Therefore this scenario also includes a 45 meter buffer along the improved Caracol road where tourism development could occur in the form of shops, restaurants, services, etc., and a further 500m buffer where current vegetation is changed to agriculture.

The agriculture expansion scenario changes areas that are currently natural vegetation to agriculture, north of the CMCC protected areas, as well as some areas in the northern part of the protected areas, and major expansion of border incursion agriculture within protected areas. These new agriculture areas were drawn by workshop participants as a “worst case scenario” of agricultural expansion. New agriculture areas north of the protected areas were modeled a bit differently, to reflect the use of mechanized production systems, while southern agriculture (e.g. within the protected area borders) does not include mechanized production.

The mining scenario was also generated from specific areas drawn by workshop participants, as places where they were concerned that mining, particularly illegal mining, could expand. These were digitized from the workshop maps and incorporated into the baseline land cover. These mining areas were changed from their current natural vegetation to bare ground, indicating the deforestation that occurs.

Finally, the timber scenario considers what happens if the existing forest in Mountain Pine Ridge, Chiquibul Forest Reserve, Caracol Archeological Reserve, Vaca, and Elijio Panti, as well as the western part of Chiquibul National Park, were opened to short-term timber leases, leading to unsustainable logging. This was based on the location of current timber concessions, as well as areas identified by workshop participants where they were concerned about unsustainable logging, or saw the opportunity for continuing sustainable extraction. Sustainable logging is believed to have little to no significant impact on hydrologic services, while unsustainable logging creates more erosion and runoff during the rainy season.

Figure 4 shows the combination of all of these “unconstrained” (e.g., worst-case) development scenarios. Note that the type and extent of developments in these scenarios are those envisioned by stakeholders as a possible future for the region, if development were not regulated sustainably under an integrated plan. In some cases this includes an expansion of illegal activities that are currently not well controlled; in other cases this represents an expansion of development that could be achieved if current rules are changed or are not adequately enforced. Evaluating the impacts of this extensive development scenario allowed us to understand the impacts of different development pressures on priority ecosystem services, in order to highlight areas that are more and less threatened as well as more or less sensitive to such development. The next sections describe the ecosystem services and economic models that were developed to evaluate these impacts.

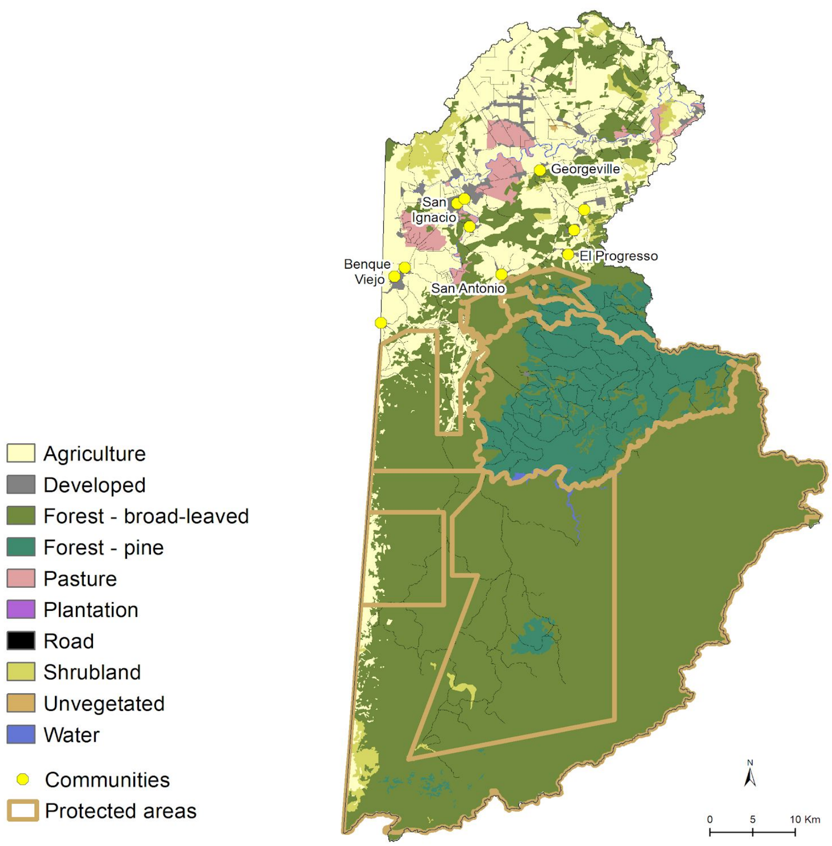


Figure 3. Current (baseline) land-use land cover map, modified from Meerman et al. 2017 and showing only the Belize side of the modeled area. Note that the western portion of the watershed, in Guatemala (not shown here), was also included in the modeling but is assumed to remain in its current condition for the purposes of this analysis.

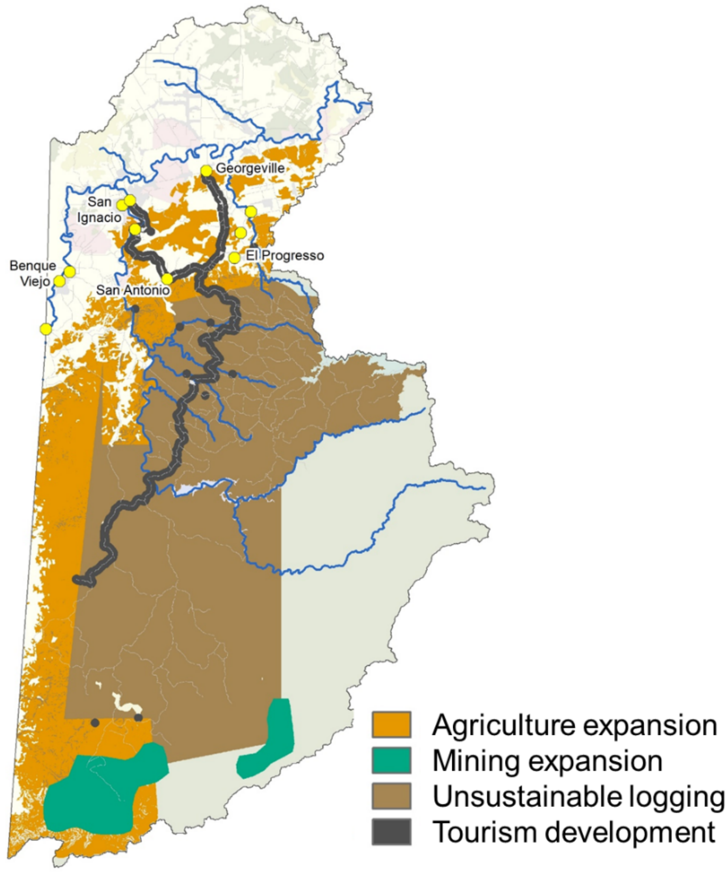


Figure 4. Unconstrained potential 20-year development scenario.

5. Methods: Ecosystem Services Modelling

Once the primary services were identified through the consultation process, we developed models to quantify and map the current provision of these services in the CMCC, as well as the change in service that may occur under the "unconstrained" development future and other land management options. A listing of the models used in this analysis are given in Table 2.

The Natural Capital Project's InVEST toolset provides geospatial models for quantifying water flow, nutrient and sediment delivery to streams and carbon stocks. Custom spreadsheet (non-spatial) models were also developed to value tourism, timber and agricultural production. A brief summary of each of these models and results follows. See the Technical Appendix for a detailed description of the modeling and related data.

Because the CMCC is connected through hydrologic flows with the surrounding landscape, the scale and extent for which services are mapped and modeled must be larger than the scale of the SDP and the policy scenarios considered therein. In this case, the headwaters of the Mopan River originate in Belize in the CMCC before flowing into Guatemala. The river travels north and then flows back into Belize before being joined by the Macal River (also originating in the CMCC). Besides the local communities of San Ignacio, Santa Elena, Cristo Rey, San Antonio, Georgeville, Upper and Lower Barton Creek, and El Progresso, the streams originating in the CMCC and the Belize River provide much of the surface water supplies to the downstream cities of Belmopan and Belize City. Therefore, the area for modeling water-based ecosystem services includes portions of eastern Guatemala, the CMCC, and the buffer areas to the north along the Mopan, Macal, and Belize Rivers (Figure 5). While water from the CMCC flowing into the Belize River ultimately provides drinking water for Belize City, there are approximately 107 river kilometers from Belmopan to the water intakes for Belize City, with many other developments influencing water flows and water quality along this stretch. Therefore, for this study we include the Belize River downstream only as far as Belmopan.

Table 2. Ecosystem service models used in this analysis

Ecosystem service	Model	Used for	Link to Documentation
Water flow and availability	InVEST Seasonal Water Yield	Modeling changes in quickflow and baseflow due to land cover & management scenarios	User's Guide
Water quality	InVEST Nutrient Delivery Ratio	Modeling changes in nitrogen loads due to land cover & management scenarios	User's Guide
	InVEST Sediment Delivery Ratio	Modeling changes in erosion and sediment loads due to land cover & management scenarios	User's Guide
Carbon	InVEST Carbon	Modeling changes in carbon stocks due to land cover & management scenarios	User's Guide
Tourism & recreation	Tourism, spreadsheet model using available data and assumptions of development intensity.	Estimating changes in tourism revenue due to land cover & management scenarios	See Section 6.1
Timber	Timber, spreadsheet model based on average per-hectare production and revenue from historical data.	Estimating timber production and revenue changes under land cover & management scenarios	See Section 6.3
Agricultural production	Agriculture, spreadsheet model based on average per-hectare crop mix and production values from historical data.	Estimating agricultural production [and revenue] changes under land cover & management scenarios	See Section 6.4

5.1. Water flow & availability

The InVEST Seasonal Water Yield (SWY) model estimates the amount of water produced by a watershed, arriving in streams over the course of a year. The two primary outputs of the model are quickflow and baseflow - quickflow represents the amount of precipitation that runs off of the land directly, during and soon after a rain event, and baseflow is the amount of precipitation that enters streams more gradually through sub-surface flow, including during the dry season.

Data inputs to the Seasonal Water Yield model include climate, topography, soil and land cover. A national land cover map of Belize (Meerman 2017; Figure 3) was combined with a national land cover map from Guatemala to produce a consistent land cover mapping across the entire watershed that encompasses the study area. The land cover map was modified to include roads, while the other model inputs were derived from global datasets, since local sources were not available.

To understand which areas of the landscape are contributing more or less water to streams over the course of the year, we combined the quickflow and baseflow results from the model, to produce a total annual water flow map, given in cubic meters per year. These modeled results were calibrated using observed outflow data from Vaca dam, and from river gaging stations at Cristo Rey and Benque Viejo.

Further, information on water demand was collected, to account for additional water withdrawals that might result from different development options.

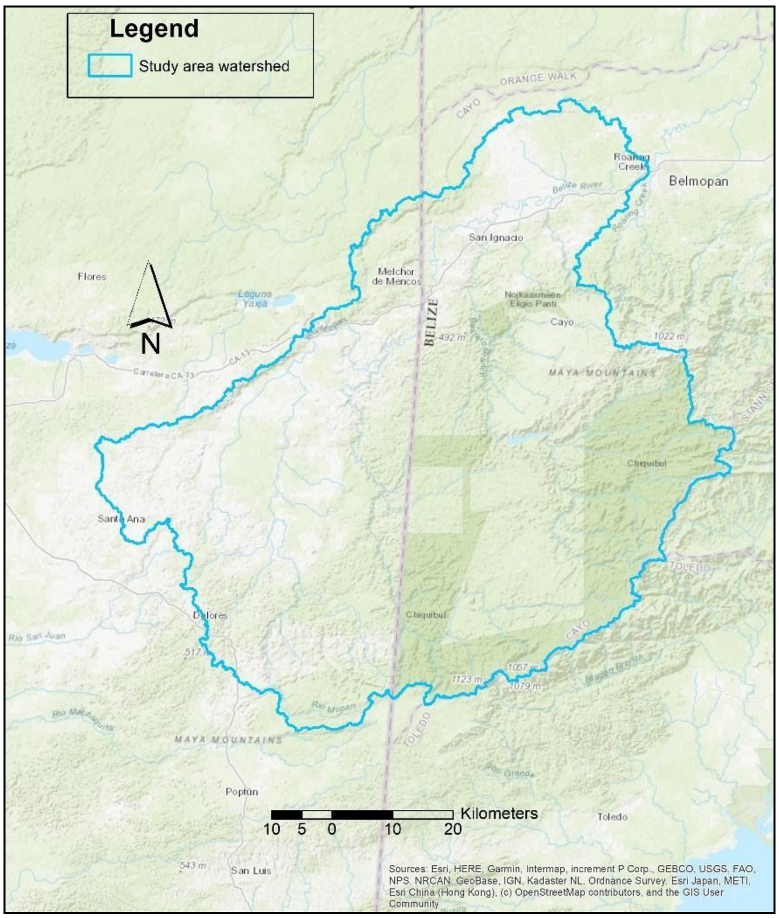


Figure 5. Extent of study area for modeling water flow and water quality. The watershed boundary was delineated based on topography (30m DEM) and includes the buffer communities downstream of the CMCC region that depend on the area for their source water.

5.2. Water quality

Two InVEST models were used together to evaluate water quality, the Nutrient Delivery Ratio (NDR) and Sediment Delivery Ratio (SDR) models. The NDR model was used to map the sources of nitrogen on the landscape (primarily running off of agricultural areas), show which areas are helping retain some of this nitrogen so it does not end up in streams, and quantify how much nitrogen arrives in streams, which may affect downstream users. Similarly, SDR helps us see where higher levels of erosion are occurring, which areas are providing the service of retaining some of that erosion, and quantifies the amount of sediment that arrives in streams. Sediment in streams decreases reservoir storage, may carry pathogens, and reduces water clarity, which impacts recreation uses.

Inputs to the NDR model include land cover, topography and water runoff, and SDR requires land cover, topography, soils and climate data. As with Seasonal Water Yield, the modified Meerman 2017 national land cover map was used, and the other model inputs were derived from global datasets. Regional values were used for the model parameters that pertain to nitrogen loading and erosion potential by land cover type. Retention of sediment in the three reservoirs - Chalillo, Mollejon, and Vaca - was calculated based on the ratio of storage capacity to watershed area, and retention of nitrogen was set at 20% per dam as part of calibrating the model outputs to observed data.

Several SDR and NDR model results were used to assess various aspects of water quality. Sediment deposition is a direct model output that provides spatial information on where the service of sediment retention is currently being provided on the landscape. An equivalent metric was created for NDR, to show where nitrogen is being retained by vegetation. These two metrics were combined to create the water quality service index.

For assessing the change in nitrogen or erosion arriving at particular points of interest, such as reservoirs or recreation sites, the nitrogen export and sediment export model results were used. These quantify the amount of nitrogen or sediment that is not retained by the landscape, but enters a stream, potentially impacting downstream users. Nitrogen export is given in kilograms per year, and sediment export in tons per year. Observed data for nitrogen at San Ignacio was available from the Ministry of Natural Resources for calibrating the NDR model, but observed data were not of sufficient extent and quality to allow for calibration of the SDR model. The results from the NDR and SDR models were normalized and combined into an index of water quality service, which is used in later steps to reflect the change due to the development scenarios.

5.3. Carbon

The InVEST Carbon model maps land use/land cover types to the carbon stocks contained in their biomass. Again, we used the modified Meerman 2017 land cover map, and assigned global average values of aboveground and belowground carbon to each land cover type. The results provide total carbon stored across the landscape, in tons of C per pixel. Unlike previous studies that consider the carbon stored only in forests and natural ecosystems (which typically store the most carbon per unit area), our approach considers carbon stored in many different types of land uses.

5.4. Beneficiaries & cumulative impacts

In order to best manage an area for multiple benefits, it is important to gather data and generate maps of areas where people are currently benefiting from ecosystem services, and where they are likely to benefit or suffer from changes in ES when different land management decisions are implemented. These are the “beneficiaries” of ES, and their location and distribution are typically different depending on the services considered.

During the first stakeholder workshop in July 2019, participants drew on maps of the CMCC area, indicating the location of places that were considered assets to the communities, threats to those assets, or opportunities for the future. This information was digitized and represents the most comprehensive mapping of the environmental assets in the region to date. Using this information, we delineated the areas that contribute services to each of the existing assets, as described below.

Communities, as well as recreation sites, resorts and hydropower facilities, all benefit from an ample supply of clean water throughout the year. Each of these beneficiaries can be represented with a point along a stream where drinking water is withdrawn, or where the recreation site or reservoir is located. The upstream area that flows into each point represents that point's watershed, where development can affect the quantity and quality of water experienced by communities, tourists, and other users.

In order to understand which areas within the CMCC contribute water, nutrients, and sediment to these different points of interest, we used the InVEST tool DelineateIt to define the watersheds draining to each point. Since some of these sites lie along the same rivers, their contributing watersheds overlap, so summing the number of overlapping watersheds provides a count of how many downstream sites benefit from water production and water quality protection from each upstream area.

The resulting beneficiaries map may be used alone to visually understand which areas in the CMCC development can impact greater or fewer numbers of downstream users (Figure 6). Note, however, that the cumulative impact shown in Figure 6 is not proportional to the total number of people impacted; in fact the entire study area is critical for providing clean, flowing water to the cities of Belmopan (population approx. 16,500) and Belize City (population approx. 58,000), among others. The cumulative potential impact is also combined with the service maps of water flow and water quality in later steps of the analysis, to create a weighted map showing where each service provides the greatest benefits to the largest number of sites.

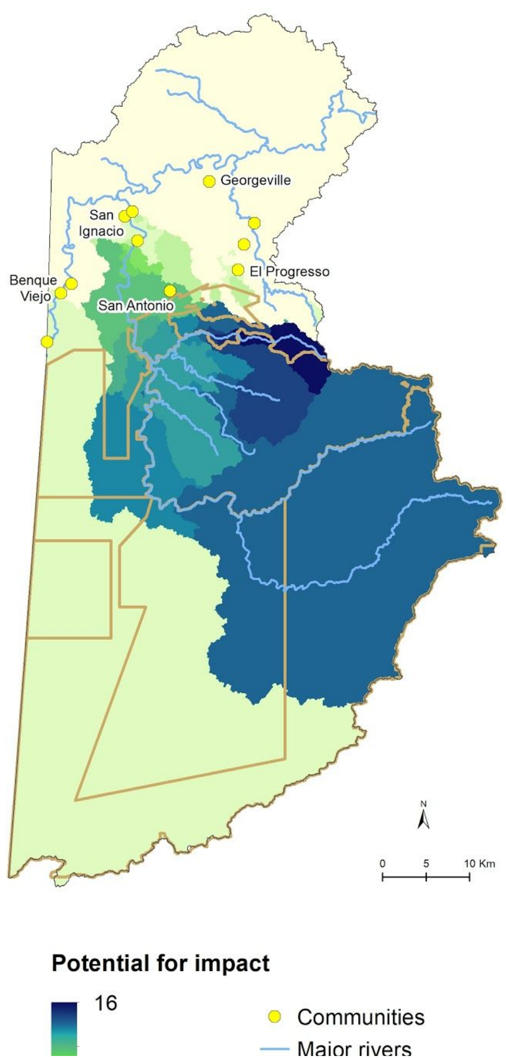


Figure 6. Cumulative potential impact to critical assets and communities. Areas with darker blue shading are those where development has the potential to impact the water flows and water quality for the greatest number of downstream assets,

communities, etc. Areas in lighter green are those where development impacts a fewer number of critical assets and communities. Note, however, that the cumulative impact here is not proportional to the number of people impacted; in fact the entire study area is critical for providing clean, flowing water to the cities of Belmopan (population approx. 20,620) and Belize City (population approx. 61,700), among others.

6. Methods: Economic valuation

Services for which robust economic valuation could be developed include tourism, carbon, timber, agriculture, and hydropower. Services for which data were not available for robust valuation include water flow and availability (for drinking water and recreation impacts), and water quality (for drinking water and recreation impacts). Instead, changes in those services are reported in terms of biophysical changes only (e.g. change in water flows, impacts of sediment and nitrogen loading on water quality).

6.1. Tourism

Data were compiled from the Belize Tourism Board (BTB) on tourist visits at the level of Cayo District, from 2012-2018. These data include: the number of hotels, the number of rooms, and the average room rate (BZD). In addition, BTB reports historic trends (2015-2018) on the number of visitors to the Cayo district. In addition, data on accommodations, average room rate and occupancy rate were compiled by UB-ERI from a review of available data online (e.g. TripAdvisor) and by reaching out directly to local businesses. While the data on occupancy and room rates are incomplete, they give a useful basis for comparison with the district-level data provided by BTB, and confirm that the CMCC area currently draws a higher price premium than neighboring areas in the district (Table 3).

Table 3. Tourism statistics for the CMCC region and Cayo District

	Number of hotels	Total rooms	Average occupancy rate	Average room rate (BZD)
CMCC region	27	162	42%	\$769 (range \$393 - \$1,140)
Cayo District	155	1704	40%	\$265

We estimate baseline average tourism revenue from the CMCC area using the data given in Table 3. Changes in tourism revenue from development options in the CMCC are based on estimates of how additional tourism business will change the average occupancy rate (currently 40% for Cayo district) and the number of rooms. In addition, for both baseline and scenarios we take into account the multiplier effect of tourism. According to the 2015 IADB tourism loan, the multiplier effect of tourism expenditure in Belize, indicative of employment and social distribution impacts, was 1.64. These results will focus on changes in tourism revenue. Due to high levels of uncertainty a sensitivity analysis will be conducted.

6.2. Carbon

Development in the CMCC region will result in a change in the carbon stock as land cover is converted to or from natural forest, timber management, agriculture, mining, and tourism development. The InVEST Carbon model estimates carbon stock (in tons C) due to the configuration of land use and management in each scenario. The results are converted to tons CO_2 equivalents, and multiplied by the price of carbon to arrive at the total value.

The Forest Trends Ecosystem Marketplace Report on State of the Voluntary Carbon Markets 2017 reports the average market price of carbon at $3 USD. Since the market prices of carbon credits do not include the social cost of carbon (SCC), which monetizes the cost of emissions in terms of welfare, for the valuation of carbon sequestration service from a social perspective it must be used at the market price plus the SCC. Nordhaus (2017) estimated the SCC globally. For the Latin American Region, it determined that the SCC is $1.87/ Ton$CO_2$e.

Adding the average market price with the SCC gives a total price for carbon of $4.87 USD ($9.74 BZD), which is within the range of typical carbon prices used in similar studies in Belize (see, for example, Kay et al. 2015 who use $4.80/ton average).

6.3. Timber

Depending on the extent and location of any development undertaken in the region, it could lead to an increase or decrease in timber production. Impacts on timber production are reflected in this analysis as changes in revenue from timber production, and reflects differences in forest type - pine and broadleaf species. Timber in Belize is sold on both local and international markets for multiple species, and we focus on the international market for various broadleaf species, and also consider the local market for pine.

The economic benefit of timber for wood products is typically measured by stumpage value—the amount per unit area that a commercial wood cutter is willing to pay for an area of standing trees (Helms, 1998). It is the product of the stumpage price and the amount of timber offered for sale. Stumpage prices for private timber are determined by the market (Sedjo, 2006).

Data on broadleaf species (mahogany, cedar, rosewood, barbajote, Santa Maria, nargusta, and sapodilla) came from Bull Ridge Ltd (2017). The sawn lumber produced (boardfeet annually) for each broadleaf species was based on the schedule of timber production provided by Bull Ridge Limited (2017; Table 78). This is done on the basis of the average stock survey results over the period 2009-2017 and Bull Ridge Limited's roundwood to sawn lumber conversion rates of 2016. The annual cutting area for broadleaf species was assumed to continue with the current plan, consisting of a 25-year rotation with two 500-ha compartments (1,000 ha) harvested annually. For the 2019 annual plan of operations 1,921 trees were harvested, which is approximately 717,949 board feet for all species, but less than 50% was mahogany (826 trees). Considering the market prices of the 7 species considered, this results in an annual revenue of $3,200 BZD from each hectare of broadleaf forest.

There are two species of pine that were included in the analysis, *P. caribaea* and *P. patula*. Data for pine came from Pine Lumber Co Ltd. (2018). Based on the information in that report, 88.1 hectares was used as the annual area to be harvested for pine. Although the long-term annual allowable cut is said to be 9,958 m^3 (equivalent to 351,672 ft^3), they concede that this long-term cut is not achievable until the forest has recovered from its current, degraded state (due to former unsustainable logging and bark beetle infestation). Therefore the annual allowable cut for the next 10 years of 3,012 m^3 (equivalent to 106,368 ft^3, or 1,276,413 board feet) was used as a conservative estimate for the SDP planning period. Board feet per hectare was then calculated based on annual board feet for pine over 88.1 hectares. The price of $1.05 USD per board foot was taken from Table 21 of the Bull Ridge Limited (2017). This calculation results in an average annual revenue of $32,100 BZD from each hectare of pine forest.

The total area of pine and broadleaf forest in the CMCC was calculated using the modified baseline land cover map. The total present value of potential timber production in the region is estimated based on the total hectares of pine and broadleaf forest, the average annual revenue from each hectare, estimated over a 20-year time horizon. We use a mid-range discount rate of 8%, and report a high and low range of values based on a range of 4% to 12% discount rates.

6.4. Agriculture

The value of land for agricultural production depends on the types of crops grown there, their productivity (e.g. pounds produced per acre), and the market price for those crops. Data were obtained from the Ministry of Agriculture on crop types, acres harvested, and average yield for the Cayo District from 2000-2018. We used an average of the last 5 years' data to represent the baseline (current) scenario of agriculture production. Since data on crops grown in the region are non-spatial, it was not possible to identify exactly which crops are grown on which parcels, and similarly, which crops would be most likely to expand to new areas. Therefore, we calculated a weighted average of crop production based on the average yields and the relative extent of each crop type. Crop prices for major crops were obtained from the Ministry of Agriculture's Weekly Retail Market Price Report, and the Belize Ag Report (http://agreport.bz/).

Further, we distinguish between the average revenue from agricultural land with a mix of crops that includes some mechanized agriculture (the most likely pattern of expansion in the northern part of the study region), and average revenue from land that does not include mechanized agriculture in the mix of crops. This calculation results in an average annual revenue from a hectare of cropland to be $6,320 BZD (including some mechanized production) and $8,300 BZD (without mechanized production).

6.5. Hydropower

There are three operational hydropower plants in the CMCC region: Chalillo, Mojellon, and Vaca. Our analysis focuses on the relationship between changes in total water flows into the three dams, and how these flows affect hydropower generation and therefore revenue to BECOL. The relationship between water flow and energy generation was estimated based on a simple regression from the production and flows data obtained from BECOL.

Data on flow (water elevation, both min and max) on total production (kWh) were obtained from BECOL for all three dams monthly from 2006-2019. In addition, we know the total capacity of each plant, Chalillo at 7MW, Mojellon at 25.2M, and Vaca at 19MW and the gross storage for all, Chalillo at 124Mm^3, Mojellon at 1.61Mm^3, and Vaca at 11.75Mm^3. Based on information from BECOL, we know that the current price of energy is 0.1161 USD/kWh at both Chalillo and Mojellon and .08297 USD/kWh at Vaca. According to BECOL, on average production is at 45%-50%. In 2019, production was at one third of the normal rate.

Using this regression, changes in inflows to the reservoirs is converted to changes in power production and revenue for BECOL. It is important to note that the price for hydroelectric power in Belize does not change even when the water is low, as BECOL has a Price Purchasing Agreement in place with Belize Electricity Ltd to purchase power at a set cost. Based on the historical production data, the average annual revenue from hydropower generation at the three dams was estimated at $50.5M BZD. Net present value is estimated over a 20-year time horizon, using a mid-range discount rate of 8%, and also reporting a range of values based on a 4% and 12% discount rate.

7. Results

7.1. Current ecosystem services from the CMCC

The following maps show results from the modeling of ecosystem services, based on the current situation (baseline land use). The following results from the Seasonal Water Yield model are shown for the direct model outputs, representing the total water flow from the landscape (the "potential" service), then weighted by the map of beneficiaries (the cumulative potential for impacts), to arrive at the water flow service. The water flow service is the realized ecosystem service, that is, the map highlights the areas that provide the most water flow to critical assets and communities downstream. Again, it is worth noting that the lighter areas in Chiquibul National Forest are critical for providing water flow and groundwater recharge for larger cities downstream - such as Belmopan and Belize City - but because we are focused on critical assets and communities in the CMCC region and its buffer, these maps highlight areas providing the most benefits to those areas.

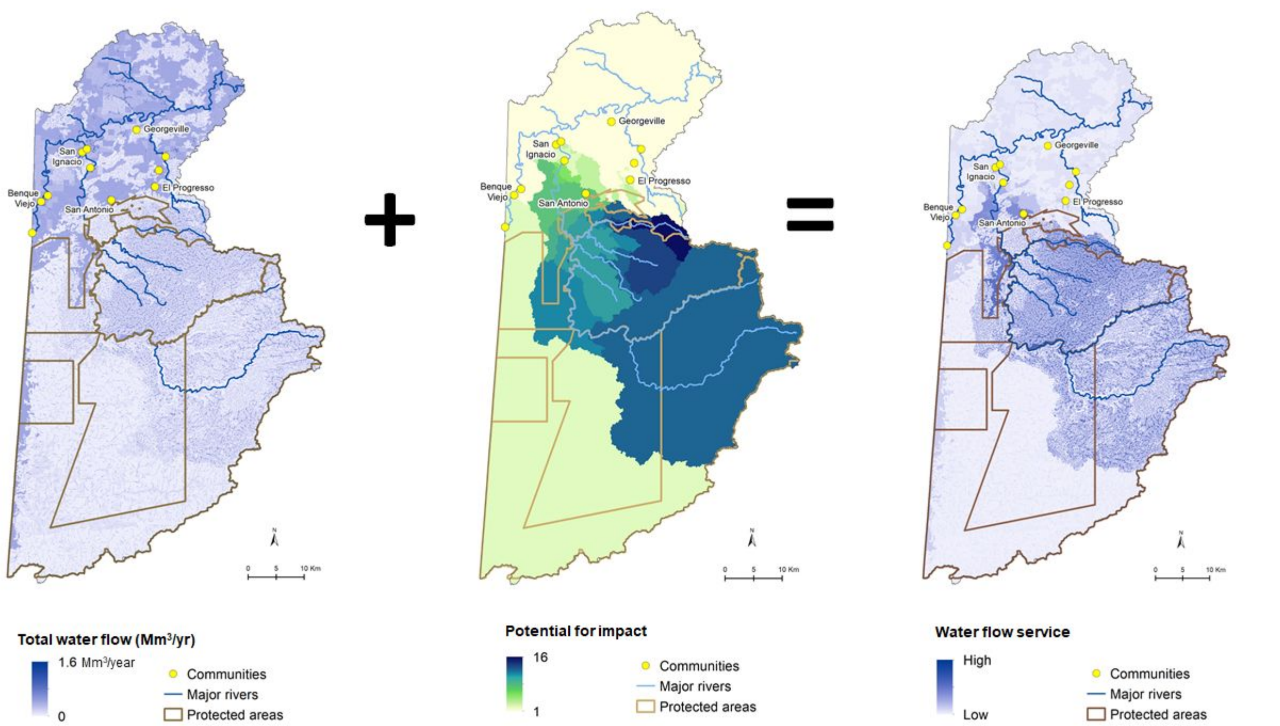


Figure 7. Water flow service from key watersheds. Left map shows the total water flow as a direct output of the InVEST seasonal water yield model; the middle map shows the cumulative potential for impact map (see Section 5.4); the right map shows the realized service: water flow weighted by the number of critical assets and communities dependent upon it.

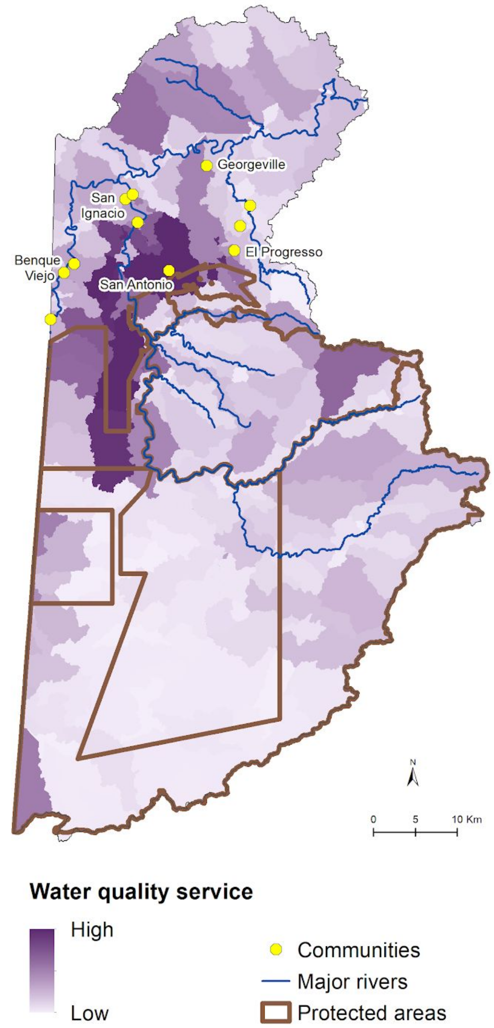


Figure 8. Water quality service from major rivers. This map shows the results from the InVEST sediment and nitrogen models, weighted by the number of critical assets and communities that depend on the water purification service.

The water quality index (Figure 8) reflects areas where the retention of sediment and nutrient is highest, thereby preserving water quality. In addition, it reflects where people are most dependent on that water purification service. Areas that are particularly important for providing water quality protection tend to be the remnant natural areas and forests that are interspersed with agricultural lands in the northern buffer zone (dark purple area, Figure 8). The MPR and the eastern portion of Chiquibul National Park also appear as critical areas for water quality protection.

The remaining forest areas and riparian zones, particularly in the MPR, the Chiquibul National Park and Forest Reserve, and Caracol, contain critical natural habitat and help to safeguard the biodiversity heritage of Belize. In this area are five different forest types, 5,000+ species of fauna, 662 species of flora, and it is also home to several rare and endangered species (e.g. jaguar, ocelot, margay, scarlet macaw and Baird's tapir) (Kay et al. 2015). Preservation of these biodiversity assets are critical to maintain both the natural and cultural heritage of the area, as well as preserving the adventure experience that is central to the unique tourism products offered by this region.

Natural areas and biodiversity also contribute the most to carbon storage and sequestration on the landscape, as shown in Figure 9. Other beneficial activities currently practiced in the region include research & education, military training camps, harvesting of xate and other medicinal plants, mining granite, gold, as well as new proposed solar energy development (BECOL, personal communication).

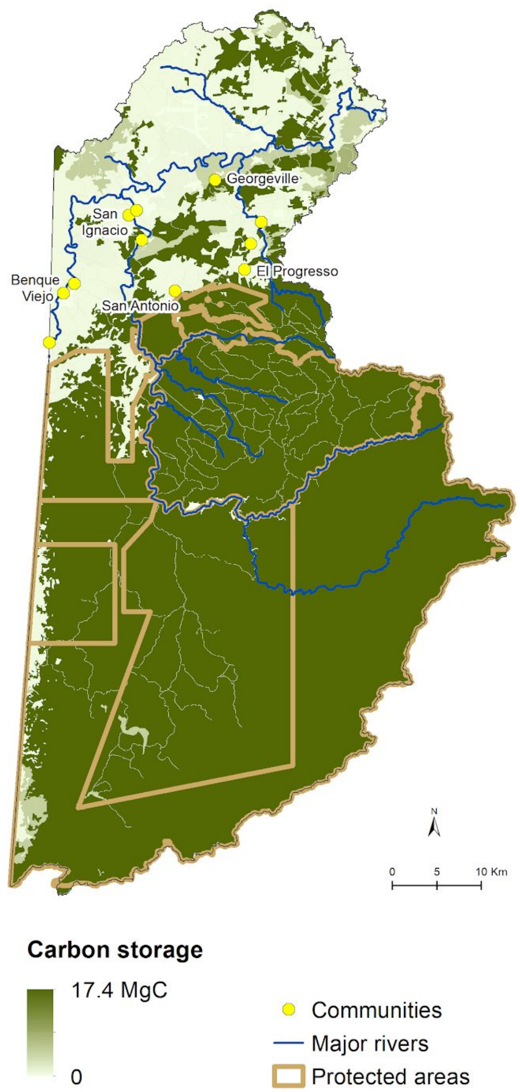


Figure 9. Carbon stored in forest and other vegetation

7.2. Economic benefits

Table 4 summarizes the benefits and values of the ecosystem services assessed in the CMCC, under the current management. The values of tourism are based on historical revenues, existing accommodations and visitation rates. Similarly, the values for agriculture are based on current agricultural areas, historical crop yields and prices. Hydropower values are based on historical energy production. In contrast, the total values for timber and carbon sequestration represent potential values, based on the current extent of the two forest types and carbon stored on the landscape. In the case of timber, not all forests are under active timber licenses currently; in the case of carbon, a program to enable the government to realize the income on the carbon market for this region has not yet been established.

These values are a useful basis for identifying potential trade-offs from changes in land use and management. Any decisions that change the footprint of areas currently in tourism, agriculture, timber, etc. will result in gains or losses in the economic value accruing to that sector, and corresponding gains or losses in the other sector(s) which are displaced. Further analysis of specific development options is needed to estimate the change in economic value for each option.

Table 4. Estimated economic benefits from the CMCC region in the current situation.

Benefit	Extent or Magnitude	Value (BZD)	Total Present Value* (BZD)
Water flow	816M m^3 / yr	Hydropower Habitat & biodiversity Drinking water Crop production Recreation/tourism	
Water quality protection	9 communities 27 resorts 8+ recreation/tourism sites	Drinking water Recreation/tourism Habitat & biodiversity	
Tourism	27 resorts 8+ recreation/tourism sites	$14.9M /year	$126M to $218M
Timber	Active concessions: 45,500 ha (broadleaf) 10,600 ha (pine) Total: 100,000 ha	$3,200 /ha/yr (broadleaf) $32,100 /ha/yr (pine)	$75M to $165.5M
Carbon	1,508,000 tonnes	~$5 /$CO_2$ equivalent	$53.9M ($90.1M incl buffer)
Hydropower	Vaca, Mollejon, and Chalillo	$50.5M /yr	$428 to $737M
Agriculture	6,600 ha	$8,300 /yr	$263M to $454M $462 to $796M (incl buffer)

* Present value ranges are reported using a range of discount rates, from 4% to 12%, typical ranges used for these types of analyses. Economic values for water flow and water quality were not possible given the available data, so instead we list the sectors impacted.

7.3. Risks and trade-offs of full development in the region

Results from analysis of the unconstrained, full development scenarios reveal areas that are both under high development pressure and sensitive to impacts on ecosystem services (Figure 10). A full accounting of the changes in water flows, water quality, and carbon that impact each type of asset (dams, communities, water features and resorts) are provided at [this link](). The results highlight that if the availability of natural assets is not balanced with the demand from development sectors, it could seriously hamper potential growth. In particular, if illegal agricultural expansion is not checked along the border with Guatemala and in Vaca Forest Reserve, there is the potential for massive impacts on ecosystem services including water, carbon storage, habitat quality, massive impacts on cultural assets such as Caracol, and loss of corresponding revenues from timber and tourism. Continued expansion of illegal mining shows similar potential for damages to sensitive ecosystems and future economic development through eco-tourism.

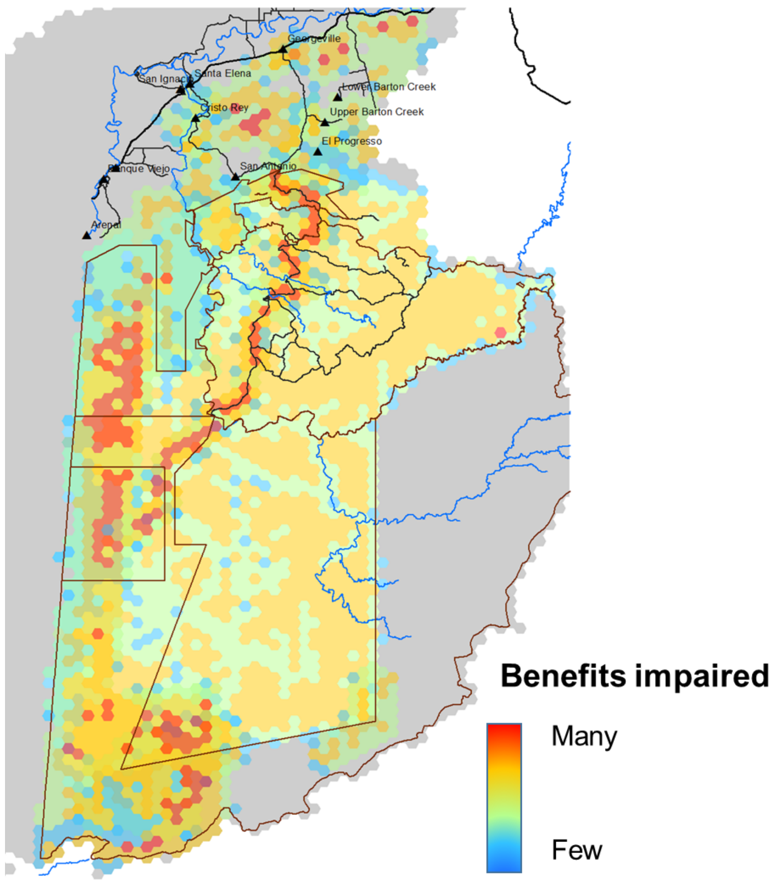


Figure 10. Projected impaired benefits from unconstrained development in the CMCC region. These results are a compilation of the full development scenario impacts on water flow, water quality, and carbon. They reveal areas where both development pressure and impacts are likely to be highest.

For instance, results show that 90% of existing resorts and half of water-based recreation sites see reductions in streamflow during dry seasons. Hardest hit would be Cristo Rey waterfall, which loses 84% of its 2.5 Mm^3 of baseflow under a scenario of large-scale agricultural expansion, and Pinol Sands, which could see 17% of its 6 Mm^3 of water lost on average during the dry season. Agricultural expansion is also the largest threat to baseflows for resorts in the area, many of which rely on local water supplies for their everyday operations.

Another major concern revealed by our analysis is that large-scale tourism development and agricultural expansion could greatly increase impervious land cover, increasing the risk of storm runoff and risk of flooding. This includes recreation sites (e.g. water features) such as Pinol Sands that could see doubling of stormflows, and Rio Frio Caves where flows increase 67% during the rainy season. These could cause seasonal shut-downs due to safety concerns, threaten roads and new infrastructure.

Most communities also see small reductions (up to about 12%) in water availability during the dry season, which given the models of climate change, could be exacerbated in the future. The impacts for water quality are highest for small source water areas. For example, the watershed for Privassion Creek/San Antonio encounters a 40% increase in nutrients and five times increase in sediment under the full development scenarios. Such an increase in pollutants could clog intakes, require more frequent cleaning to preserve storage in tanks, and necessitate additional water quality treatment and/or infrastructure.

8. Potential development activities

The results from the full development scenario are useful to inform general zoning rules that integrate the potential for development (development pressure) with the potential for negative impacts on ecosystem services. They also lay the groundwork for envisioning specific development options that can form the basis of an SDP for the area. We begin with general zoning recommendations, then lay out some specific development options to be analyzed using the models described in the previous sections.

8.1. Zoning recommendations

A framework for assessing such impacts and suggesting development zones is shown in Figure 11. The framework divides the area into four zones based on these two factors: (1) low development pressure, low potential for negative impacts on services; (2) high development pressure, low potential for impact; (3) low development pressure, high potential for impact; and (4) high development pressure, high potential for impact. General zoning recommendations derived from this framework are given below (Figure 12).

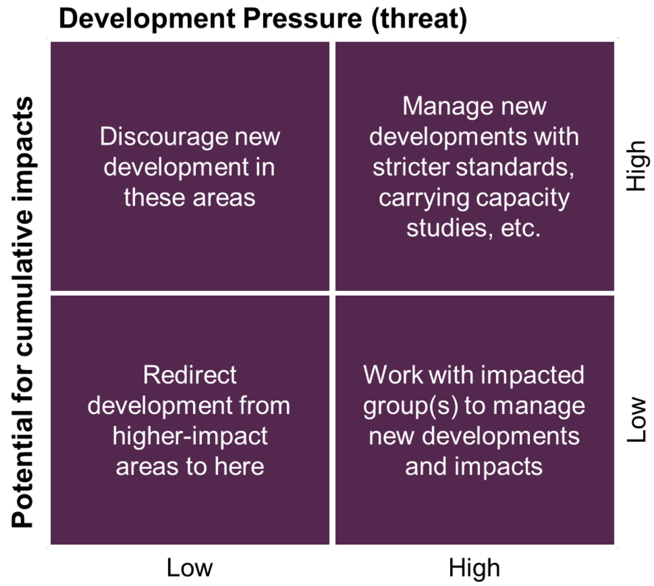
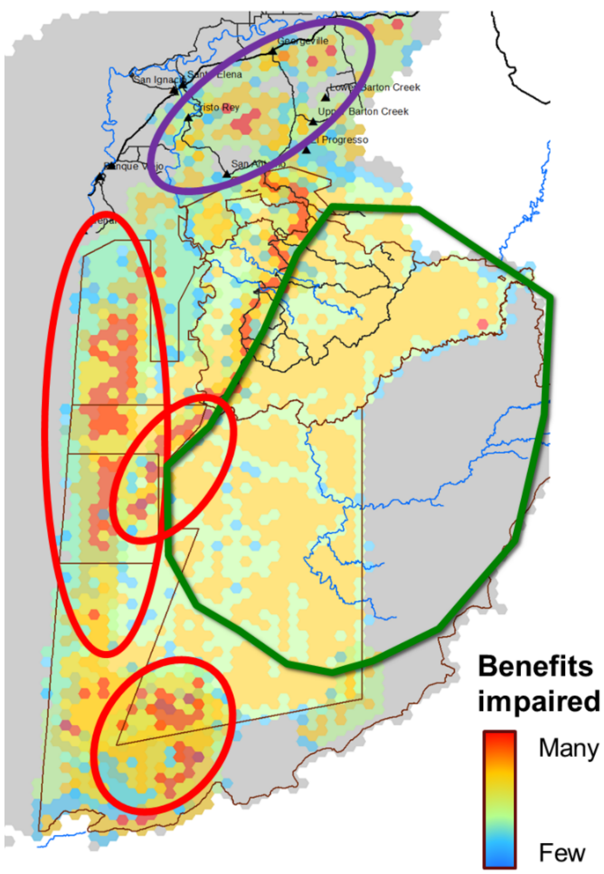


Figure 11. Framework to determine zoning options



Areas with low threat + high importance for benefits:

- Maintain and support current, low-impact practices: low-volume tourism, sustainable timber harvest, restore pine beetle damages

Areas with high threat + high potential impact:

- Maintain security outposts and prevent encroachment into Caracol and Vaca

- Continue working to restrict access to illegal incursions in the south

- Require a higher level of scrutiny for any development proposed along the Caracol road from Guacamayo Bridge to Caracol Archaeological Reserve

Areas with high threat + lower potential impact:

- Consider allowing sustainable agricultural expansion in buffer area to meet demands of growing populations and tourism market

Figure 12. General zoning recommendations based on modeling results and the framework given in Figure 11.

8.2. Development options and scenarios

In consultation with stakeholders, we developed alternatives for specific development options that should be considered for the final trade-off analysis and inclusion in the SDP (Table 5). These options span different sectors and are divided into more- and less-conservative options, representing a palette of choice for stakeholders and decision makers to choose from.

Table 5. Sustainable development options suggested for final trade-off analysis.

	Component	Most conservative options	Less conservative options
Tourism	occupancy rate	increase occupancy rate in existing hotels/resorts to 60% (50% increase over current)	increase occupancy rate in existing hotels/resorts to 80% (double current)
	new accommodations/ infrastructure	new infrastructure built as infill in communities along Caracol & Georgeville Roads; no change in urban footprint	new infrastructure built in communities communities along Caracol & Georgeville Roads; some expansion of urban footprint
	Douglas D'Silva development	some improvement, for research use only	implement improvements recommended in STP2, for tourism + research use
	sensitive tourist sites	Limit access to all sensitive tourism sites; require carrying capacity studies and management plans to be developed	Limit access only to most sensitive tourism sites; require carrying capacity studies and management plans to be developed
	Macal River	only low-impact tourism allowed along the river and in Chalillo Reservoir; restrict (seasonal?) activities in scarlet macaw breeding areas	only low-impact tourism activities allowed along the river; rafting, boating etc. allowed in Chalillo Reservoir
	hiking and camping activities	improve hiking trails, signage, in MPR only	improve/expand trail network; develop camping facilities in MPR and connect into Chiquibul (e.g. to natural bridge)
	community involvement in tourism	build capacity and incentives for communities to offer services as tour guides, cultural tourism, agro-tourism, home stays, lodging, restaurants, shops, services, etc.	
	support and promote national tourism	invest in and incentivize domestic tourism to this area, to prepare for expected drop in international tourism in the short-term due to COVID-19.	
Agriculture	Ag expansion into protected areas	No further expansion allowed; stop all illegal incursions and land grabs. Develop alternative livelihoods.	
	Ag expansion outside protected areas	No expansion beyond existing impacted areas.	Expansion allowed around communities into natural lands, with riparian buffers and strict EIA enforcement
	Sustainable ag practices	Promote sustainable use of existing ag lands thru crop selection, improved practices, organic agriculture.	
	Ag currently in protected areas	Reclaim protected area lands that have been illegally settled and restore them to natural forest	Prevent any new incursions
	Riparian buffers	Restore streamside buffers in existing ag land (outside PAs)	Enforce streamside setbacks in any new ag land developed

	Crop suitability	Promote use of crop suitability studies to make more effective use of existing ag lands	
	Diversified livelihoods	Encourage and build capacity for communities to offer agro-tourism, food culture, beekeeping, etc. to diversity products and livelihoods	
Mining	existing concessions	phase out all mining, let existing concessions expire	allow/renew existing concessions
	new concessions	no new concessions	no new concessions
Timber	Restoration, recovery, and sustainable forest mgmt in MPR	Forest Dept works to actively restore bark beetle-impacted areas in MPR	Integrate forests in this region into a national REDD+ system, earmark some money from that and use it to invest in forest mgmt and restoration of bark-beetle affected areas in MPR
	active management concessions	continue/renew existing concessions, following sustainable timber harvest plans	
	inactive management concessions	revoke inactive licenses and don't reissue until such time as the area is sufficiently recovered	allow license to continue/renew, but with recovery/restoration of the degraded areas as a component of the sustainable timber harvest plan.
NTFPs		build capacity and incentives for xate cultivation to reduce degradation in PAs	allow community members to harvest medicinal plants (and xate?) in PAs

In addition to the above development options, we recognize that regardless of the specific set of development options, other development activities will need to be promoted throughout the region in order to make best use of the natural and cultural assets there. For example:

- Research & education: promote use of the Forest Reserves and National Park as research and teaching laboratories, citizen science, and science-based tourism.
- Tourism: new infrastructure to support safety and sanitation at most popular sites as per recommendations of STP2 project; develop new eco-tourism products (canoeing, hiking, camping, etc.)
- Understand carrying capacity: New studies should be commissioned to determine sustainable levels of visitation and use for cultural, recreational, and touristic sites, both within and without the protected areas, and site management plans developed accordingly.
- Military training: Military training activities are likely to continue, and integrated planning is needed to ensure that these activities do not pose any threats to other activities, such as research and tourism.
- Community harvesting of medicinal plants is an important community practice that is likely to continue. Alternatives to wild xate harvesting should be promoted to prevent further degradation of the forests.
- Mineral exploration: The Ministry of Natural Resources has indicated that they will continue science-based exploration of the currently licensed areas for mineral resources. However, any development of mineral resources can be very destructive to natural and cultural assets, and should be carried out only with strict enforcement of EIA regulations.

- Solar energy development: BECOL is planning new solar energy installations in the region near the Guacamayo Bridge. Based on the results of this study, we recommend that any developments take advantage of existing cleared land rather than clearing new forest, as the area along the road to the southwest of Guacamayo is a particularly sensitive area for new development.

- Fire management: Build capacity and develop fire management plans both for the CMCC and its surrounding areas.

- Emergency and disaster response: Communications and emergency response systems will need to be further developed to ensure the safety of visitors to the region.

In addition, we recommend the promotion of sustainable and efficient agricultural practices in the buffer zone. Sustainable agriculture is recommended in this SDP because it uses agricultural practices that take into account ecological cycles by promoting methods and practices that are economically viable, environmentally sound and protect public health. First, it is important to determine the best use of the land with the right crop. This methodology is being used by several countries in Latin America in the context of Land Use Planning and consists of a GIS modeling, which results in a map of land use conflicts, as a result of overlapping the map of potential land use and current land use. The resulting map allows to guide the adequate use of the soil with the short or permanent cycle crop that is most adapted to the physical characteristics of the place.

Better water management, the first step in water management is the selection of appropriate crops. Local crops must be chosen because they are more adaptable to the climatic conditions of the region. Crops that do not require too much water should be chosen for dry areas. Irrigation systems must be well planned, otherwise they can lead to other problems such as river depletion, drylands and soil degradation.

Crop rotation is used primarily to maintain soil health and has a logical order chosen so that the currently planted crops can help replenish the soil nutrients that previous crops depleted. The benefits of crop rotation range from preventing disease transmission to reducing pests.

Crop diversity is another method to help protect crops against diseases and pests. Variations in the same species ensure genetic diversity, which makes crops stronger and more resilient, reducing the need for pesticides and reducing economic losses.

9. Other considerations for the SDP

The following are issues that stakeholders see are very important to the sustainable development of the area, but are not included in our modeling because we can neither quantify nor value them. These issues will be important components to consider in the final SDP.

General

- Recognize non-market values like biodiversity, cultural heritage
- Proactive planning for visitation and site management in order to maintain the integrity of cultural sites
- Consider tour guide certification program to maintain quality and protect cultural heritage

- Research & education opportunities
- Respect protected area boundaries; prevent land speculation along Caracol Road

Operations & Planning

- Need to secure assets in short term; then in long term determine carrying capacity for tourist sites and archaeological sites
- Security
- Waste disposal

Governance

- Promote and build capacity for community involvement in the tourism sector
- Capacity building to diversify livelihoods in communities
- Inclusive governance
- Land tenure regulation: Land tenure refers to the rights of individuals or communities to manage (own and use) the land on which they reside. In the process of data collection for this project, the lack of transparency on land tenure mapping was observed. It is strongly recommended that these data be updated and systematized, which will contribute to the CMCC Sustainable Development Plan in order to have greater spatial clarity with the landowners, and in addition, this information will contribute to the Land Management of this area.

10. Path forward: next steps

- Incorporate feedback from PSC to detail development options
- Present development options for stakeholder review and feedback
- Develop Sustainable Development Plan
- Revise governance options and incorporate in the SDP
- Prepare document for a final comment period
- Finalize the SDP and governance framework

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