Groundwater monitoring for mapping aquifers in Belize as a tool for climate change adaptation planning

Deliverable D.3.1 - Status and trends in the groundwater resources of Belize

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Executive summary

The National Climate Change Office of the Ministry of Sustainable Development, Climate Change, and Disaster Risk Management, and the National Hydrological Service (NHS) are implementing a project to design a Groundwater Monitoring System for the New River Watershed with funding from the Climate Technology Centre and Network (CTCN). This report has been completed as part of Output 3 of the project and provides an overview of groundwater availability, exploitation and vulnerabilities in Belize.

Overview of groundwater provinces

Belize has been divided into seven groundwater provinces as described in Hartshorn (1984), and shown in Figure 1. They are the Coastal Plains, Coastal Shelf, Campur, Vaca Plateau, Savannah, Maya Mountains and Toledo and are defined broadly on their hydrogeological characteristics. Groundwater is exploited in all seven provinces with the exception of the Maya Mountains where little groundwater exists in the igneous formations. Groundwater on the cayes is limited to small freshwater lenses, and consequently reverse osmosis is used for water supplied by BWS in San Pedro and Caye Caulker. Although the general extent of groundwater bearing formations are known, limited information exists on the hydrogeological characteristics of aquifer systems in Belize, for example in northern districts groundwater is extracted from shallow and heterogenous aquifer systems with variable yields and water quality. The quality and potential yield of deeper aquifers remains largely unexplored.

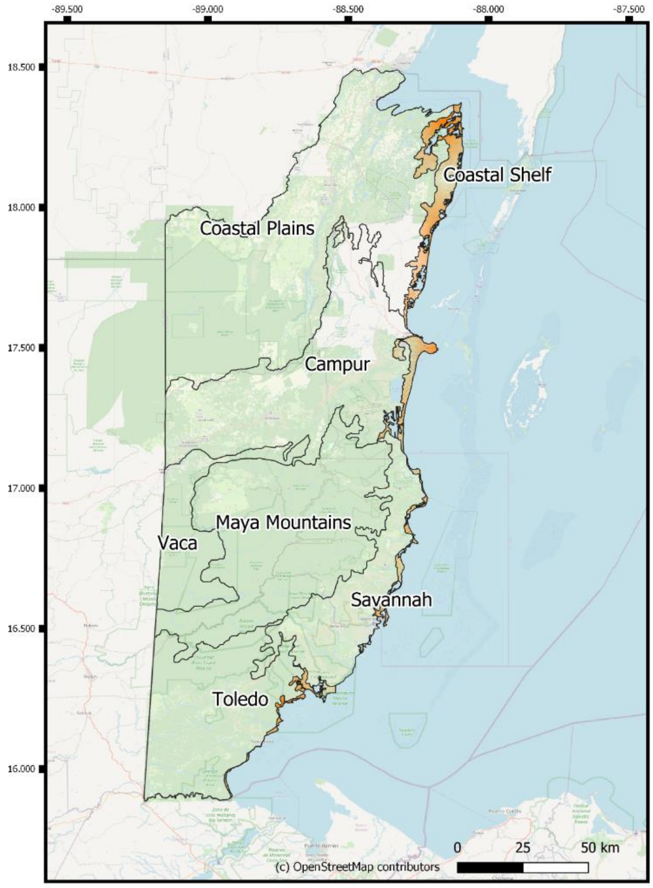

Figure 1: Belize groundwater provinces (Coastal Shelf province shaded red for clarity) data provided by the NHS. Note that the Cayes are not included in the GIS shapefiles

Table 1 summarises some relevant characteristics of each of the provinces. The columns are coloured based on the cell values. Those in red indicate high values which may put pressure on groundwater resources (for example high population, high proportion of agriculture). This simple characterisation indicates that the Coastal Plains and Campur provinces represent the more highly populated and cultivated provinces, whilst also being the driest (lowest aridity values). The coastal shelf is also populous for its small area, it notably contains Belize city as well as sparsely populated coastal areas. The remaining provinces are characterised by smaller populations, less agriculture, and wetter conditions overall.

Table 1: Summary of groundwater province characteristics

Groundwater province	**Area (km^2)**	**Mean elevation above sea level (m)**	**Population (WorldPop 2020)**	**Percentage of province classed as cropland**	**Aridity (ratio of precipitation to reference evapotranspiration)**	**Mean reference evapotranspiration (mm/yr)**	**Mean precipitation (mm/year)**
Coastal Shelf	864	9	66,393	0.1%	1.06	1,736	1,832
Coastal Plains	6612	45	92,144	23.2%	0.89	1,707	1,525
Campur	4004	51	147,931	21.0%	1.09	1,682	1,839
Savannah	1797	30	50,755	10.3%	1.43	1,676	2,399
Maya Mountains	4332	463	3,294	0.9%	1.34	1,607	2,152
Vaca	1225	456	7,626	2.9%	1.33	1,651	2,194
Toledo	2785	169	13,395	5.9%	2.01	1,608	3,236

Water consumption

Total municipal water demand has been estimated to be around 6000 million gallons per year (MG/year) (23Mm^3/year), made up of 51% from the main water utility Belize Water Services (BWS), and 41% from non-BWS sources (rudimentary water systems and private supplies). This is estimated to rise to 8150 MG/year (31Mm^3/year) by 2060 if per capita water demand remains constant.

For BWS systems in 2020, 67% of the water supplied is produced using conventional water treatment processes with rivers as the extraction sources, 27% from groundwater and 6% from Reverse Osmosis (RO) plants. However, the use of river sources is focused only on Belize City, Belmopan, Dangriga, San Ignacio and Santa Elena. Many of the smaller systems rely on groundwater abstraction. Non-BWS systems, including Rudimentary Water Systems (RWS) in rural areas and private supplies rely heavily on groundwater sources. If it is assumed that non-BWS water supplies depend solely on groundwater, then as a whole 57% of municipal demand (all sources) is met through groundwater, a total of 3400 MG/year (12.9Mm^3/year). Note that these figures are approximate and based on simple assumptions for non-BWS supplies. More detailed information on non-BWS water consumption and supply sources would refine these estimates.

Agricultural water demand based on FAO data is estimated to be in the region of 70 million m^3/year (1.85 billion gallons per year). This information dates from 2000 and it is likely that agricultural water consumption has increased over the intervening period as a result of increasing land conversion to agriculture. An updated estimate of agricultural water demand is urgently required in order to better understand its impacts on water resources.

Industrial water consumption at national level is 21 million m^3/year (5,500 million gallons per year) - or approximately 21% of total water withdrawal as a share of internal resources (based on FAO Aquastat data). This data appears to date from 2000, and therefore may not be representative of the current situation. Actual groundwater abstraction volumes for industries in the New River area for 2022 total 284,000 m^3, and are likely a substantial underestimate of the true figure. Mandatory water abstraction licencing and submission of actual abstraction volumes is recommended to increase confidence in the data, for both consumptive and non-consumptive uses.

Groundwater management

A robust water governance and management framework is required to ensure resource protection, the integrity of supply distribution, equity, protection for vulnerable groups, and to manage cross sectoral and transboundary conflicts.

Belize has embraced the guiding principles of the IWRM concept through the adoption of a National Integrated Water Resources Management Policy (including Climate Change) for Belize, 2008 which is centred on the achievement of the equitable and sustainable use of the resource. In order to achieve these goals, IWRM guidelines prescribe a multi-sectoral, fully inclusive and participatory approach to the management of the resource by all stakeholders - public, private and community; as well as the enactment of policies and legislation that limit environmental degradation and encourage efficiency in the use of the resource. The management of water resources in Belize however continues to remain fragmented.

Transboundary aquifers extending from Belize into neighbouring countries represent an additional management challenge. Groundwater from southern Mexico is believed to flow southeast towards Belize. Where the national border is defined by a river such as the Rio Hondo between northern Belize and Mexico, the river is likely to intercept shallow groundwater flowing south-east from Mexico and discharge this flow into the river as baseflow.

Strengthening the regulatory arrangements for licensing of groundwater abstraction, coupled with improved data collection on groundwater abstraction is required in order to allow the NHS to more effectively manage groundwater resources for their long term sustainable development.

Further, given the increasing threats to groundwater and surface water quality, especially in northern Belize, improved data collection and sharing on diffuse and point source pollution, coupled with actions to manage and reduce pollution, are needed to limit the risks of a long-term deterioration in groundwater and surface water quality.

Groundwater vulnerabilities

Climate change is projected to increase temperatures in Belize, while rainfall is projected to decrease. This will result in lower groundwater recharge, declining river flows and increasing crop water demands and incidents of drought. The most severe impacts are likely to be felt across the drier northern groundwater provinces and may require the increasing exploitation of deep groundwater resources in the Campur limestone formations which are believed to exist beneath the shallow aquifer systems and have been little exploited or explored to date.

Climate change in combination with increasing agricultural development and application of fertilizers, especially in northern Belize, poses a risk to groundwater resources both in terms of reduced groundwater recharge and reduced river flows, especially in the dry season, coupled with increasing contamination (and reduced dilution) of groundwater with fertilizers and pesticides. Recent eutrophication events in the New River risk becoming commonplace unless action is taken to determine the specific causes of contamination and develop mitigation measures. Proper monitoring of groundwater and surface water quality, volumes, groundwater abstraction rates and diffuse and point source pollution sources is critical to inform management actions.

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1 Introduction

1.1 Project summary

The Belize National Hydrological Service and National Climate Change Office are executing a project to design a groundwater monitoring system for the management of aquifers in Belize, focusing on the New River watershed. The project commenced in October 2022 and will complete in August 2023. HR Wallingford Limited is leading the consulting team implementing the project and financial support is provided by the Climate Technology Centre and Network (CTCN).

This important project will help Belize to sustainably manage groundwater resources in the face of a changing climate and human pressures on the resource.

The main outputs include:

1. A communications plan and detailed work plan;
2. Stakeholder mapping and establishing a stakeholder working group;
3. An assessment of groundwater availability and demand, nationally and with a particular focus on the New River watershed;
4. Design of an integrated monitoring system that will enable Belize to manage groundwater resources in the priority area of the New River watershed;
5. Development of an implementation plan on the enabling factors for implementation, including financial, institutional setting and capacity building.

1.2 Project background

In Belize, 56% of the population lives in rural areas where groundwater is a vital source for fresh water and represents almost 95 per cent of the fresh water supply in rural areas.

Groundwater is also used as a source of drinking water in the towns of the Corozal, Orange Walk, Cayo and Toledo Districts and in some rural areas of Toledo and Cayo. However, the existing aquifers and their annual recharge rate have not been quantified.

Increase in demand for fresh water resulting from increasing population, greater economic activity and agricultural expansion are threatening the quality and availability of fresh water. Each year during low rainy seasons exists the possibility of droughts due to low recharge of aquifers.

Transboundary aspects and distribution of population are other factors that affect the water sector. For example, central and northern regions (Orange Walk and Corozal) have much larger populations and higher agriculture zones for water intensive crops, but less water resources.

Although there is a need for groundwater information across the country, the priority area include the New River watershed.

The Nationally Determined Contribution (2016)[1] indicated water resource assessment (especially groundwater) as part of the main actions to be implemented to build resilience.

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[1] Belize's Nationally Determined Contribution, 2016 https://unfccc.int/files/focus/ndc_registry/application/pdf/belize_ndc.pdf

The results of the prioritization of adaptation technology factsheets for the Water Sector documented in the technologies needs assessment (TNA) for adaptation (2017)[2] include:

- Drought Monitoring System for Northern Belize with Specific Focus on Groundwater Resources;
- Water Efficient Fixtures and Appliances;
- An Integrated Management Strategy for Water Safety for Eight Rural Water Supply Systems in Belize.

The National Hydrological Service (NHS) is leading a process for building an inventory of existing data on groundwater. The objective is to identify and homogenize information that is currently available but spread among different agencies and institutions, and their various departments.

Requests have been made from the executive level of the Ministry (responsible for the NHS) to other ministries for sharing of relevant groundwater data. However, this is still a work in progress. Additionally, the Ministry of Rural Transformation has indicated that they do not geo-reference their wells.

Following the foreseen adaptation actions in the NDC and the TNA for Adaptation for the water sector, the National Climate Change Office of the Ministry of Sustainable Development, Climate Change, and Disaster Risk Management, and the National Hydrological Service (NHS) started conversations to develop a proposal for a Groundwater Monitoring System.

1.3 About this report

This report provides an overview of the status and trends in groundwater availability and consumption for Belize, and pressures on the groundwater resources.

2 Groundwater availability in Belize

2.1 Location and topographic setting

Belize is a North Central American country between Guatemala and Mexico and borders with the Caribbean Sea. The country has an area of 23,000km^2, which includes 690 km^2 of approximately 450 small islands. Belize has a long coastline bordered by a 250km long barrier reef (Miller, 1996). There are six administrative districts, as shown in Figure 2.1: Belize, Cayo, Corozal, Orange Walk, Stann Creek, and Toledo.

Topographical characteristics divide Belize into two regions, as shown in Figure 2.1:

- The Maya Mountains (and associated plateaus) consisting of Cayo district and the western portions of Stann Creek and Toledo districts, in central and southern Belize rise to 1100m and are bound by escarpments. Doyle’s Delight, at 1124m, on the Maya Divide Ridge is the highest point.
- The northern and coastal regions of Orange Walk, Belize and Corozal districts, are largely seasonally swampy plain (Miller, 1996) with low and flat elevation. The southern coastal region of the Stann Creek and Toledo consist of low elevation coastal plains with rivers draining the central mountains.

Belize is divided between tropical savanna climate in the North and tropical rainforest to the South (Miller, 1996). The mean annual temperatures range from 23-27°C and coastal regions are generally hotter than interior regions, particularly those at higher elevations (World Bank, 2022).

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[2] Technology Needs Assessment for Adaptation, 2017 https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TNA_key_doc/3db7d7bbba4c4deebecbc11fd24fb67d/5331353e87a0488e861d1fe6aca1b747.pdf

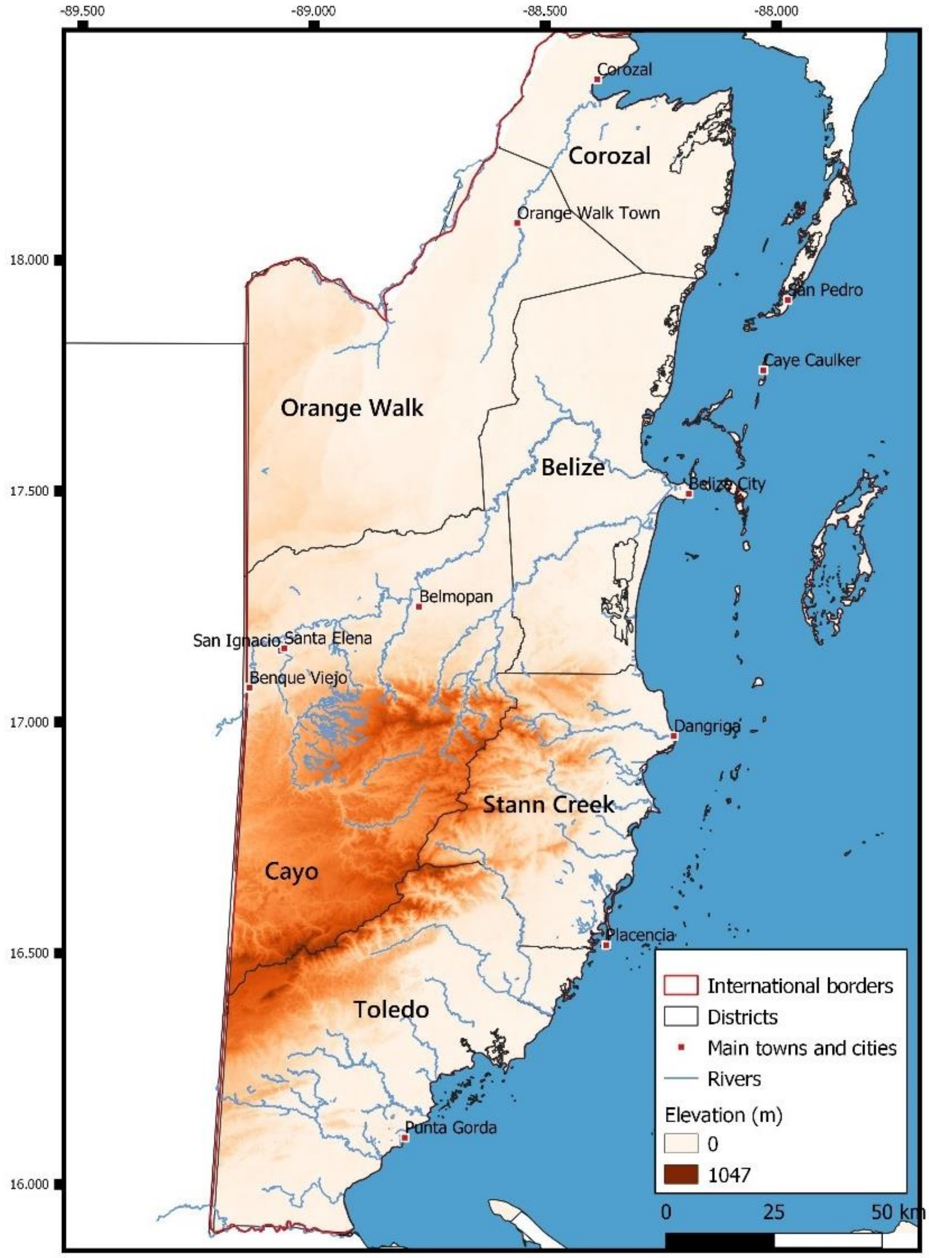

Figure 2.1: Map showing the topography and administrative districts of Belize

2.2 Geology

The geology of Belize consists of extensive limestone formations (UNDP/ Geomedia Ltd, 2014) and is shown in Figure 2.2, with legend, cross sections and stratigraphy in Figure 2.3 and Figure 2.4.

The Maya Mountains are a fault block in central Belize, bounded by the North Boundary Block and the South Boundary Block. They are composed of Carboniferous and Permian clastic and carbonate rocks and volcanics with Upper Silurian and Triassic intrusives and inliers of Upper Jurassic, Cretaceous and Lower Cenozoic sediments (Petersen et al., 2012). The Northern, Western and Southern flanks of the mountains are flat-lying Cretaceous limestones (Polk et al., 2013).

The Corozal Basin in the Northern region consists of calcareous sediments with high permeabilities (UN, 2022a). It is a complex of Tertiary limestones and marls with many shallow closed-depressions, Quaternary alluvial deposits, and swamps underlain by the flat lying carbonate deposits of Cenozoic age (Polk et al., 2013). It should be noted that Belize does not have a formal stratigraphy (King et al 2004) and that work is ongoing to refine the chronostratigraphy (King & Petruny, 2022).

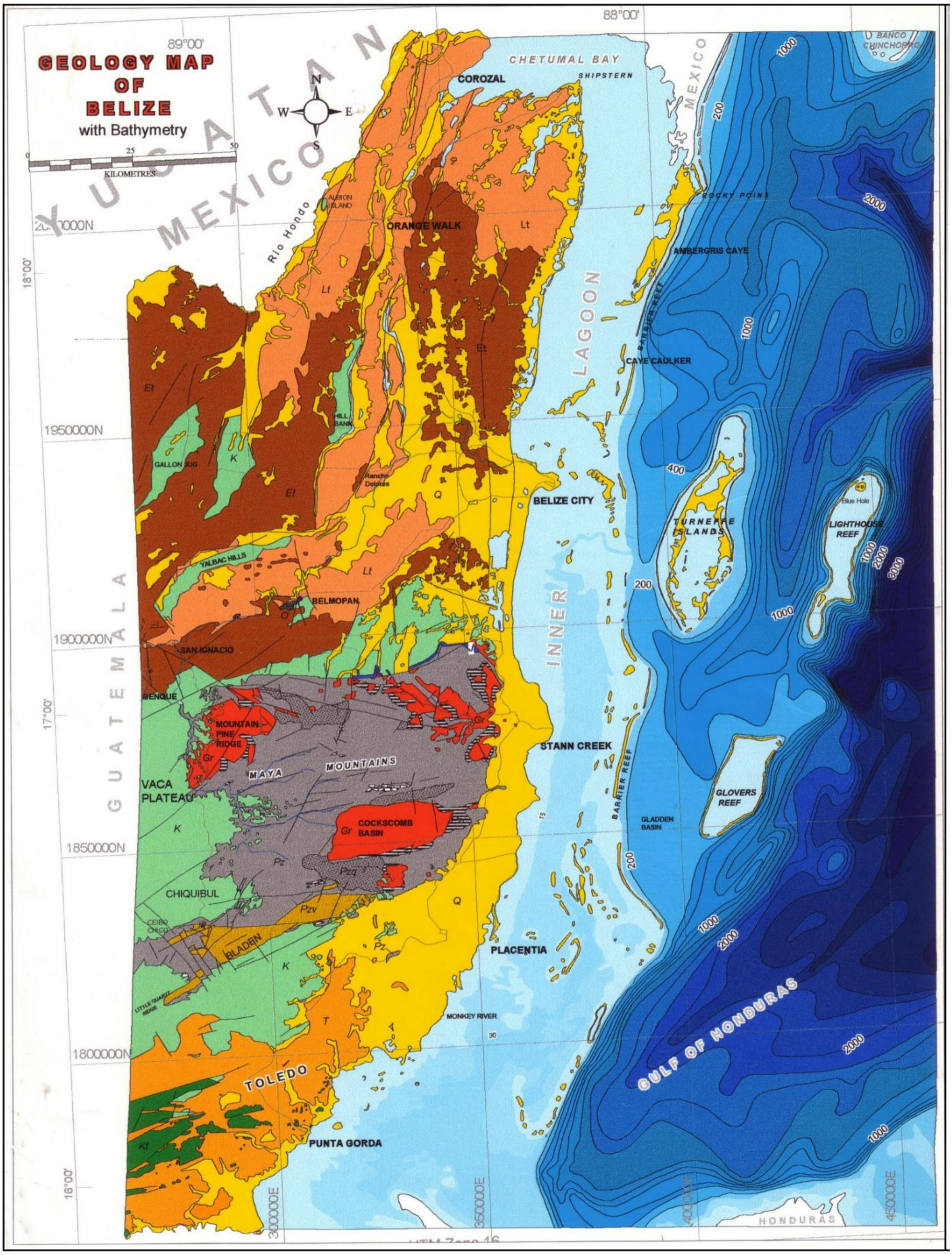

Figure 2.2: Geology map of Belize (provided by the Geology and Petroleum Department, and produced by Jean Cornec in 2003, see overleaf for legend, cross section and stratigraphy)

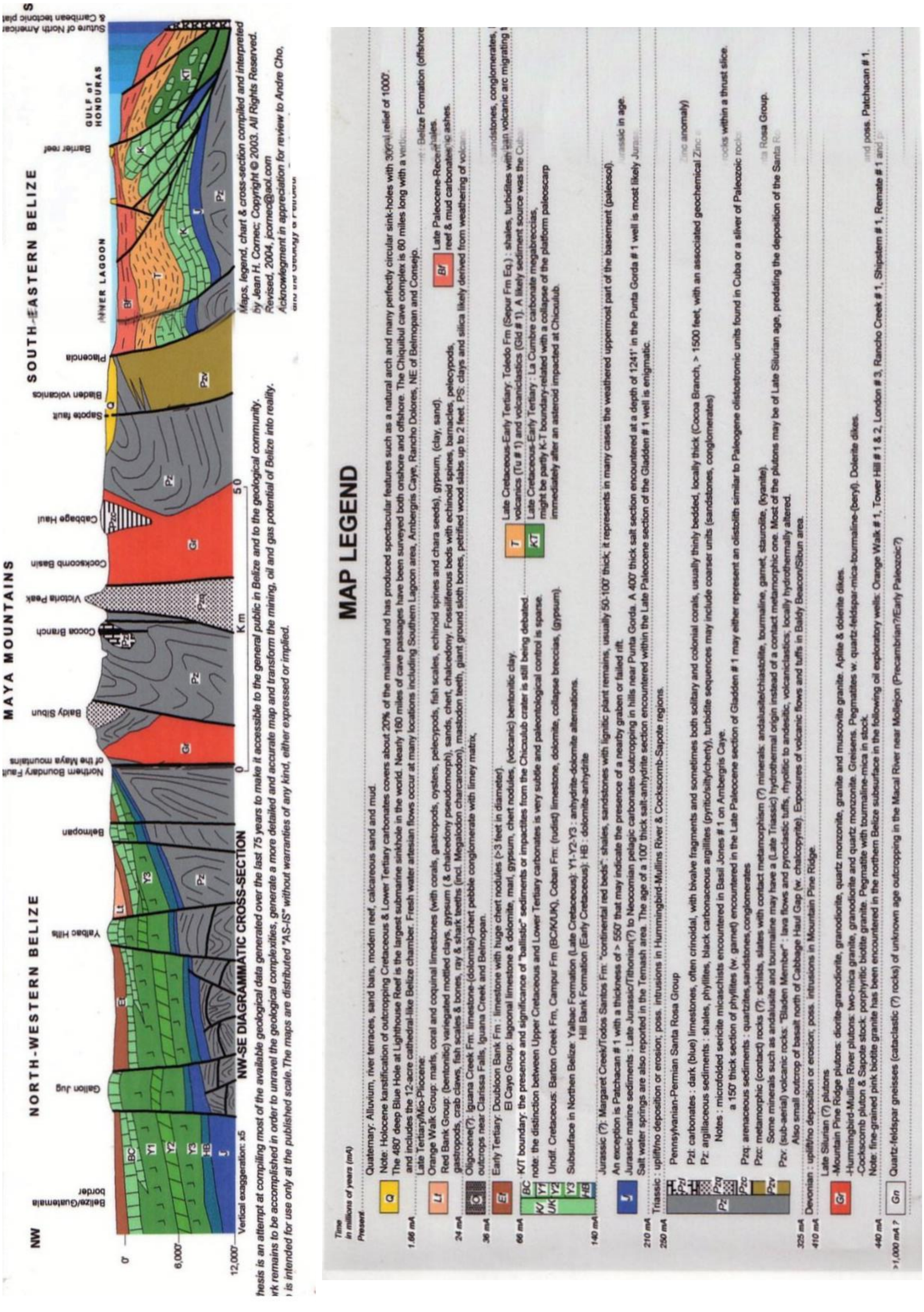

Figure 2.3: Belize Geology Map cross section and legend (Cornec, 2003)

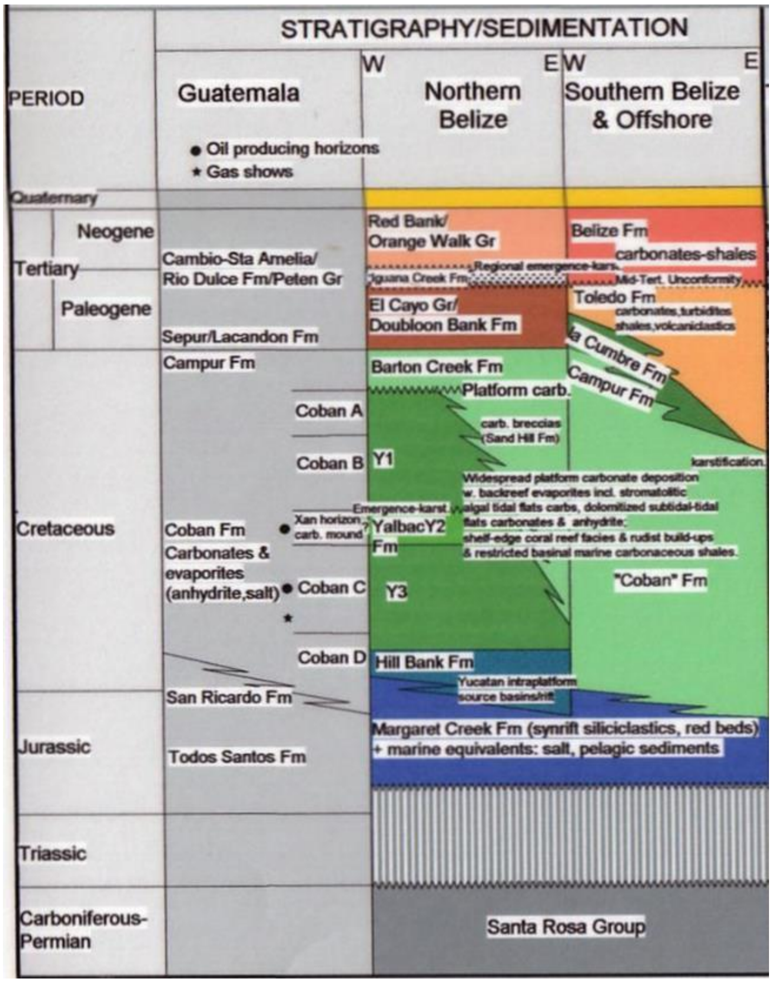

Figure 2.4: Belize Geology Map stratigraphy

2.3 Hydrology

2.3.1 Rainfall

Belize has a moist tropical climate (World Bank, 2022). The annual rainfall increases with elevation and more southerly latitude, due to the Maya Mountains in the South (Miller, 1996), as shown in Figure 2.5. The annual rainfall ranges from 1347 mm at Libertad village (Corozal district in North) to 4526 mm at Barranco village (Toledo district in the South) (UNDP/Geomedia Ltd, 2014).

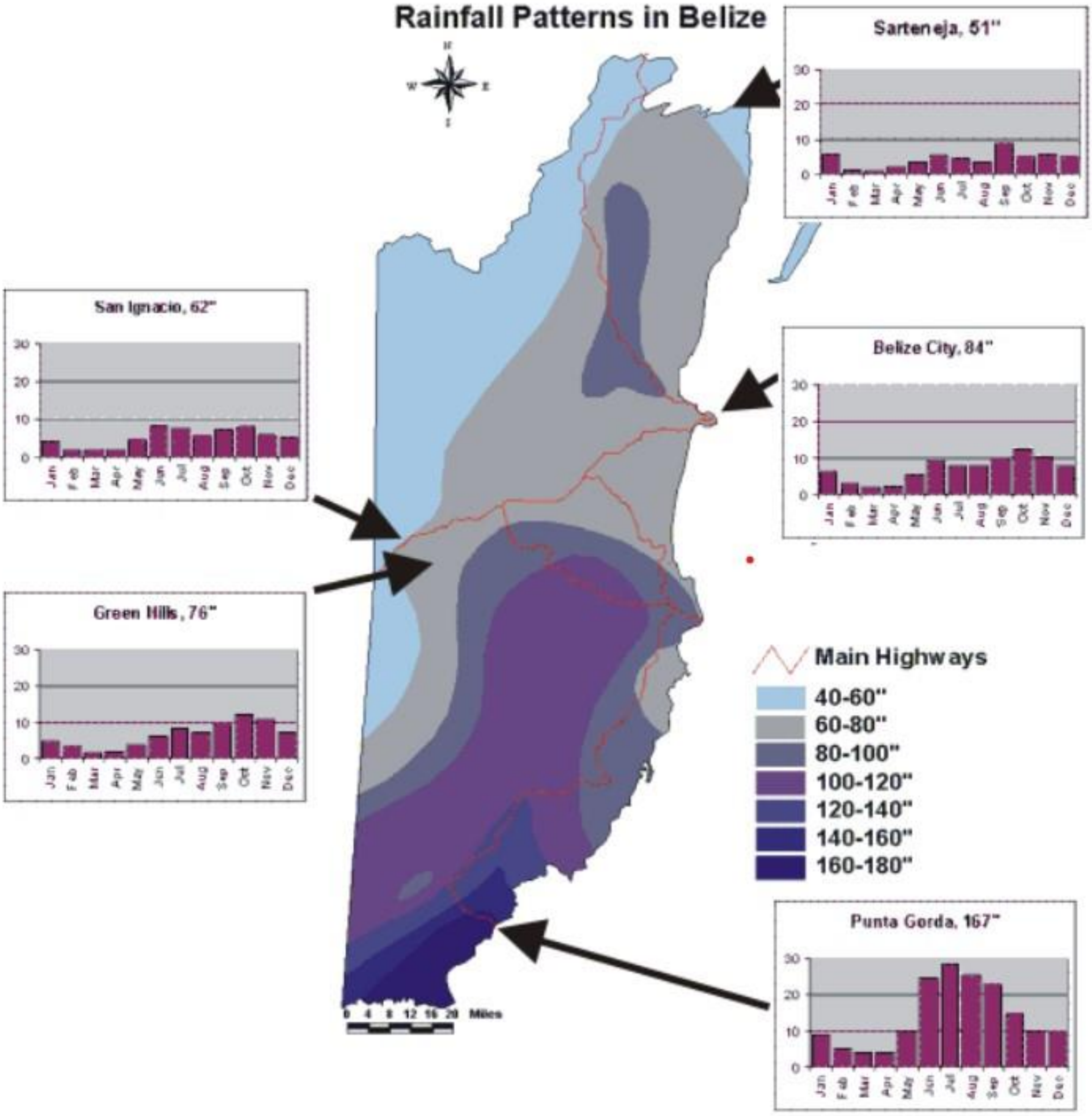

Figure 2.5: Belize annual average rainfall map (Biological Diveristy, 2011)

Seasonal rainfall effects are more significant in the central and Northern regions (UNDP/Geomedia Ltd, 2014). The variability and trends of precipitation across the seasonal cycle in Belize is shown in Figure 2.6. The wet season begins in mid-May in the South and early June in the North and lasts till November (CCCCC, 2015). During the wet season there is a mean monthly rainfall of 150-400 mm in South, whilst the rest of the country receives <100 mm per month World Bank (2022). The rainfall pattern during wet season is bi-modal over Central and Northern Belize, with a dry spell of 10-14 days in late July or August after the onset of the wet season. This is less pronounced in the South (CCCCC, 2015).

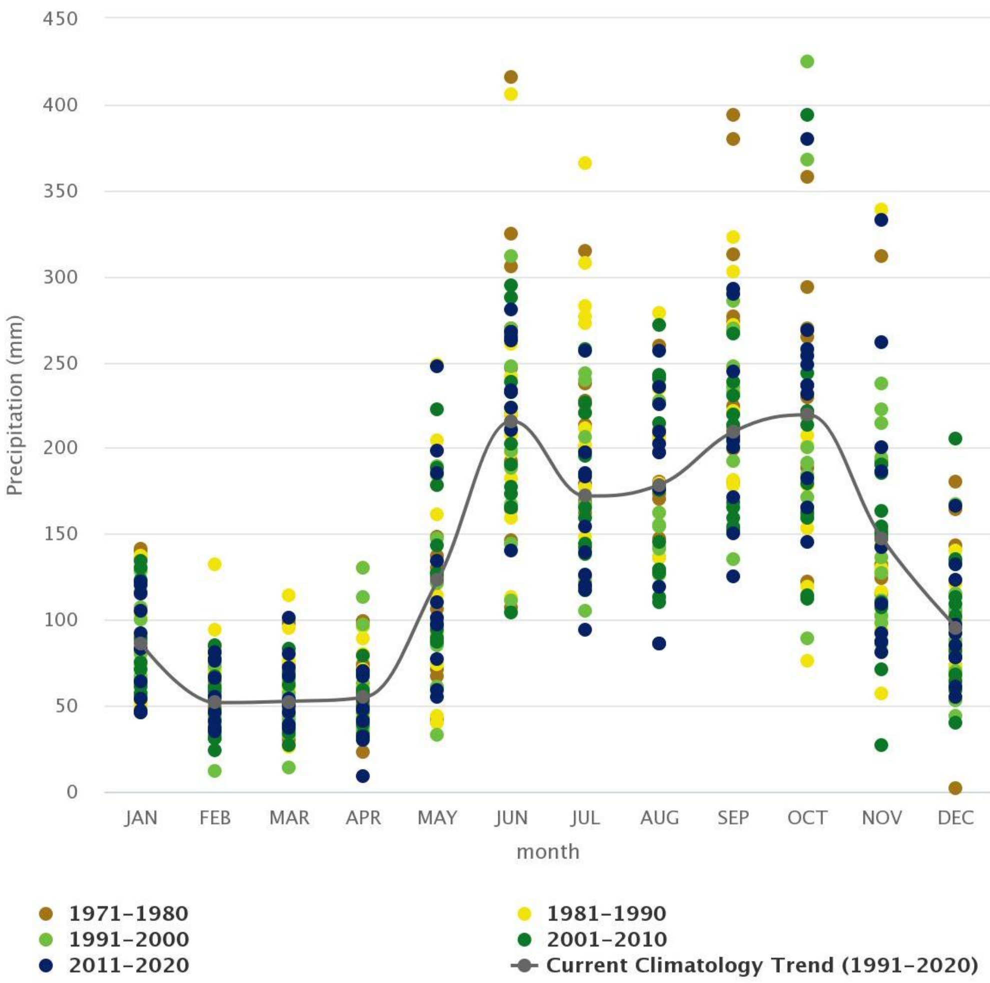

Figure 2.6: The variability and trends of precipitation across the seasonal cycle in Belize

The wet season is followed by a cool wet transition period from December until February when arctic air masses from the North move in with cooler night time temperatures. This period accounts for 11-20% of annual total rainfall for most districts in Belize (CCCCC, 2015). The dry season lasts from mid-February to May (CCCCC, 2015).

In addition to variability in precipitation during the year, Belize also experiences extreme rainfall events. In June and July tropical waves and cyclones produce localised and intense thunderstorms. During late August, September and October significant and prolonged rainfall can occur during the height of hurricane season, resulting in substantial runoff and flash floods. From November to January significant, but less intense rainfall from frontal systems can occur (CCCCC, 2015).

2.3.2 Reference evapotranspiration and aridity index

Reference evapotranspiration (ET_0) is the rate of evapotranspiration from a hypothetical short grass of uniform height, actively growing, well-watered, and completely shading the ground (FAO, 1998). It is the basis for calculating Actual Evapotranspiration (ET_a) of crops and other vegetation with the use of a crop coefficient (K_c). The Aridity Index is a measure of the ratio of precipitation to ET_0. Arid zones are characterised by a low ratio of precipitation to ET_0, i.e. there is much lower rainfall than vegetation water demand. Figure 2.7 maps both ET_0 and Aridity for Belize on an annual average basis. The maps clearly show higher ET_0 in the north, and lower ET_0 in the central mountains. Aridity is again higher in the north due to the combination of lower precipitation and higher ET_0 in the north. The ratio drops below 1 in the northern part of Belize indicating on average a ET_0 is higher than the average rainfall. However, it should be noted that this is reference evapotranspiration, not actual evapotranspiration (which varies with vegetation type and water availability), and also does not capture intra-annual variability. Figure 2.8 shows how precipitation is lower than ET_0 during the drier months December to May, indicating this period of the year might require crop irrigation (depending on crop type, soil conditions and natural variability of rainfall). The example is for a site in Orange Walk, in the wetter areas of southern Belize precipitation exceeds ET0 for most of the year, and deficits are minor. There is an increasing trend in evaporation for all seasons for the period 1980 – 2010 (CCCCC, 2015).

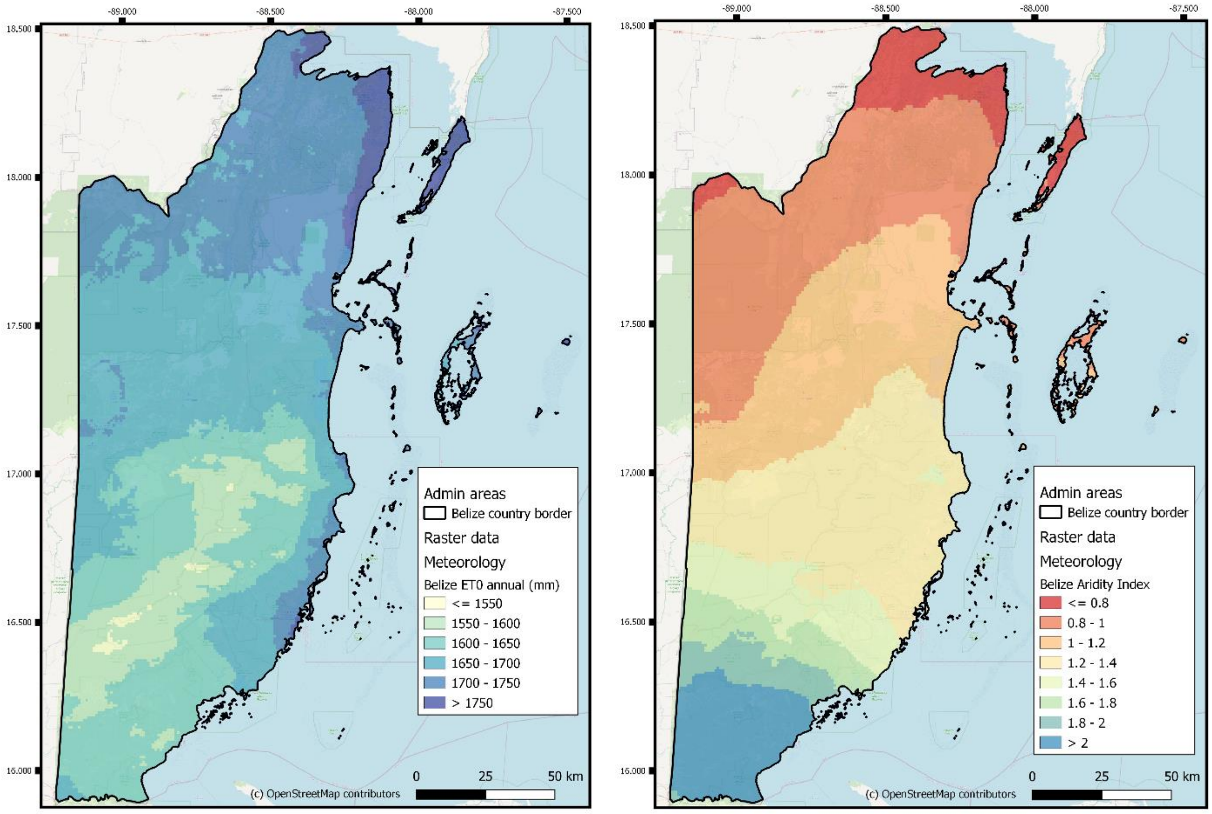

Figure 2.7: Reference evapotranspiration (ET0) and Aridity Index for Belize (Zommer and Trabucco, 2022) Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0)

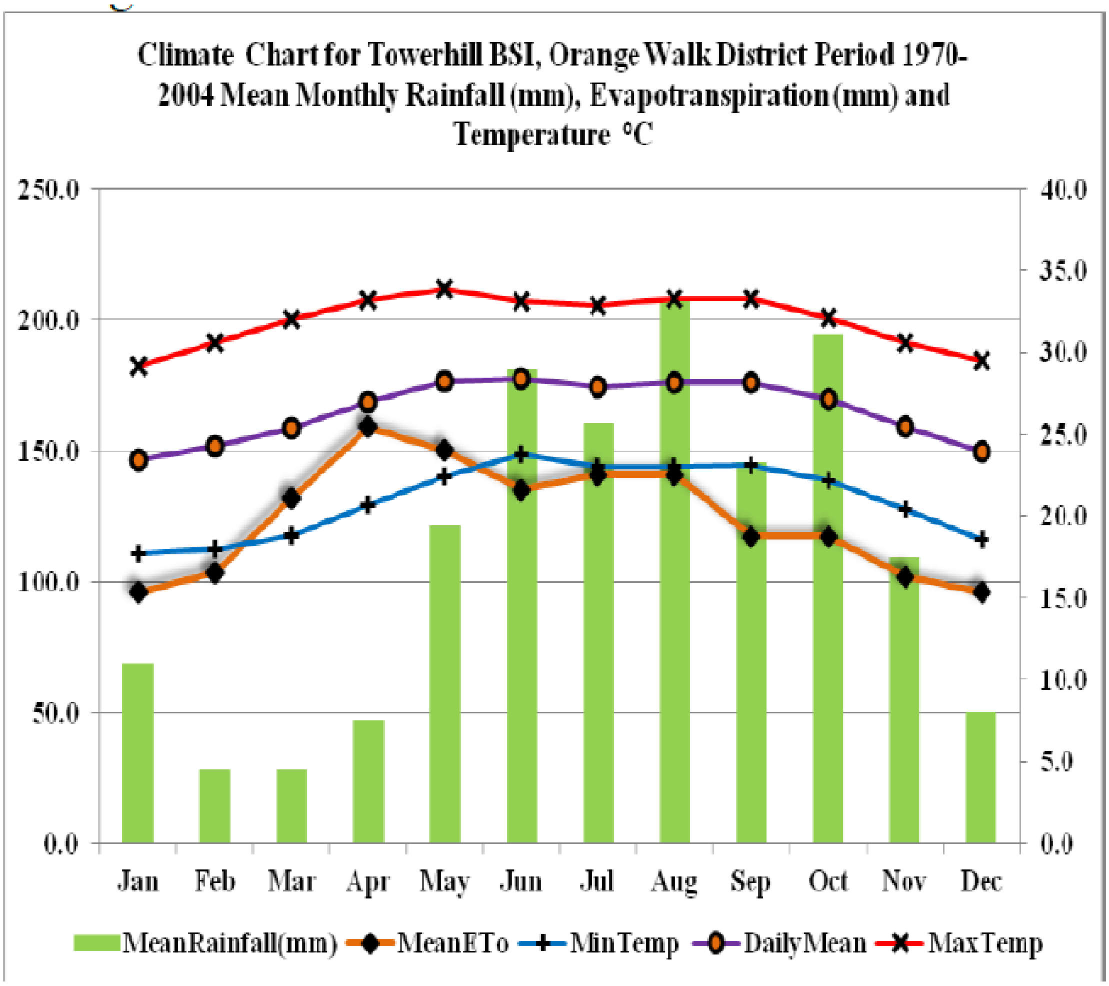

Figure 2.8: Rainfall, temperature and ET_0 for Towerhill in Orange Walk (CCCCC, 2015)

2.3.3 River flows

There are 18 major river catchments as shown in Figure 2.9, with another 16 sub-catchments which drain the Maya Mountains and discharge into Caribbean Sea. Five of the major rivers originate in Mexico and Guatemala (UN, 2022a). These rivers are the Rio Hondo, Belize River, Moho, Temash, and Sarstoon. The Northern rivers have more meanders, whilst Southern rivers have smaller basins and flow more rapidly into the sea. Surface water is not abundant on the Vaca Plateau (the high point in the Maya Mountains) as streams flow into the porous limestone.

River levels are monitored by the National Hydrological Service at 41 locations (based on the 2014 flow monitoring location map) with rating curves available for some stations. Some of the records extend back several decades and represent a very important dataset for water resources assessments and research studies, for example to quantify the impacts of climate change on water resources, understand the risks of water scarcity for key users, and formulate water allocation policy. It will be important to continue to collect and assure this dataset, developing rating curves and analysing the data to better develop knowledge on the hydrology of Belize's rivers, and how this links to groundwater resources.

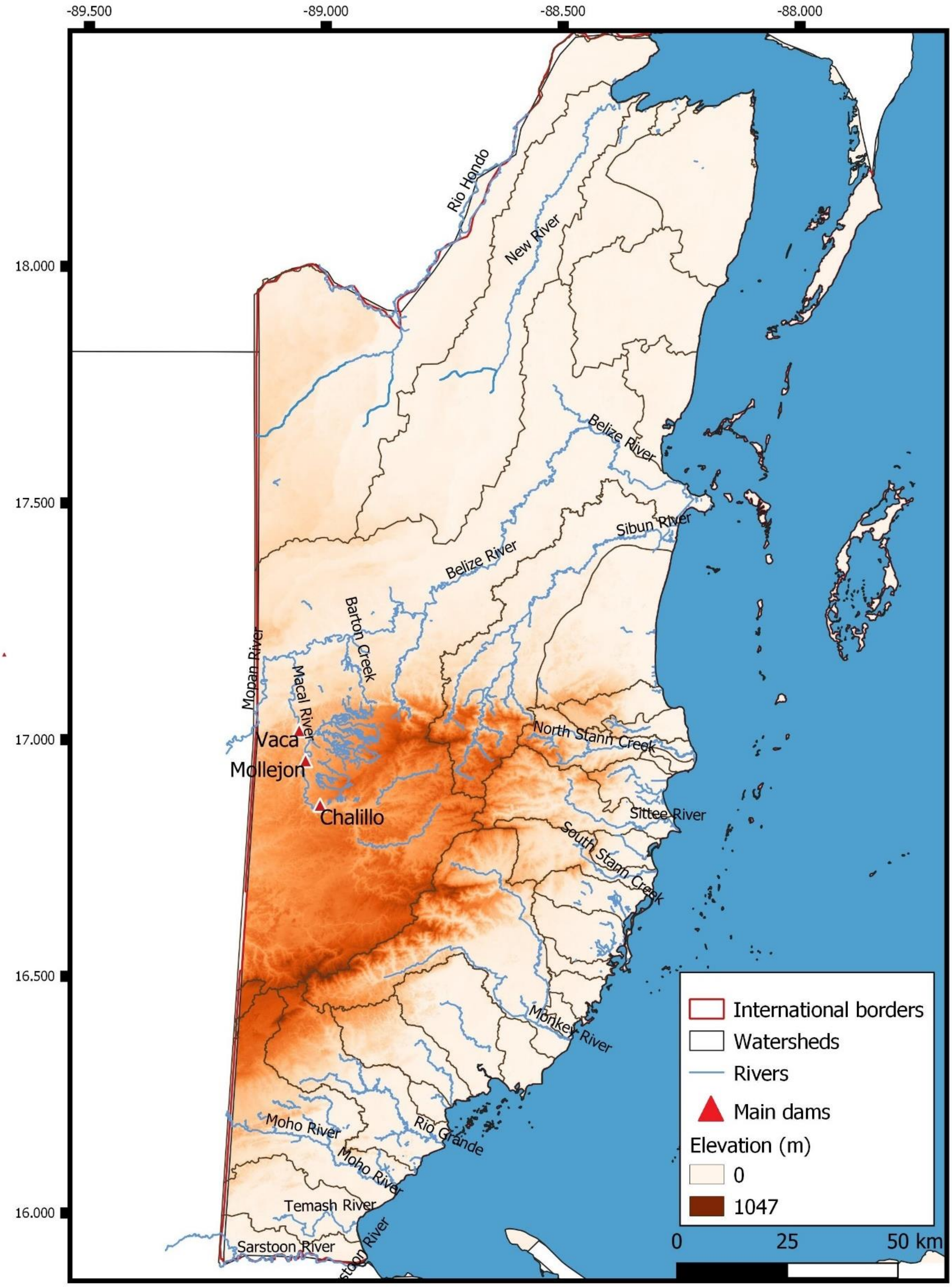

Figure 2.9: Map of Belize showing the main rivers and watersheds

2.4 Hydrogeology

2.4.1 Groundwater systems

The groundwater systems of Belize have been divided into 7 groundwater provinces, outlined by the National Hydrological Service in Figure 2.10. With the exception of the Maya mountains, aquifers are present in carbonate formations and represent a key source of water for municipal, agricultural, and industrial purposes. An overview of groundwater in each province is provided by Hartshorn et al. (1984) and is summarised below:

- *Coastal Plains* – The Corozal and Orange Walk administrative districts are included in the Coastal Plain Groundwater Province. Numerous village and private wells in this province tap into chalks and marls of Eocene age or younger. Based on a survey completed by the NHS most wells are of open construction and are less then 10m deep, reaching the water table between 1 and 10m below the surface. Drilled boreholes are typically less than 30m deep and reach the water table at similar depths as the open wells. It would appear that hydrogeological characteristics vary considerably in these shallow aquifers, which makes the success of well drilling unpredictable. Beneath these Eocene deposits are older limestone formations. These are referred to in Hartshorn as the Lacandon and Campur formations, while the more recent geology map uses different names (see Figure 2.2 and Figure 2.3). These formations outcrop in the Campur province to the south of the coastal plains where they provide reliable yields. These are presently not exploited, with the exception of a well at the Caribbean International Brewery at Carmelita which is around 200m deep and is understood to provide a reliable yield. These deeper aquifers are likely to provide a more resilient source of groundwater, although very little exploration has been carried out to determine the depths of these formations beneath the province and to quantify their hydrogeological characteristics.
- *Coastal Shelf and Cayes*– A perched freshwater aquifer exists in the extensive sand beaches particularly along the Southern coastal shelf. However, the thickness of the fresh water that floats on salt or brackish water is less than 1 meter. Most fresh water is obtained from hand-dug wells or rainwater collection. Groundwater on the cayes is limited to small freshwater lenses, and consequently reverse osmosis is used for water supplied by BWS in San Pedro and Caye Caulker.
- *Campur* – This province coincides with the *Campur limestone,* so groundwater is available, if the water bearing limestone formations are reached.
- *VACA (Vaca Plateau)* – The Vaca Plateau has no permanent towns or villages, and water obtained from springs or streams in the Chiquibul drainage basin.
- *Savannah* – Hartshorn (1984) notes there are no reliable groundwater sources and wells have limited success. However, the Savannah province was the subject of a study in 2014 'Enhancing Belize's Resilience to Adapt to the Effects of Climate Change – Assessment of Belize's groundwater resources in the southern coastal water province referred to as the Savannah Groundwater Province' (UNDP, 2014) which provided some further data and information on this province. The study concluded that only 2% of natural groundwater recharge was being abstracted at present, and only from shallow aquifers. Deeper aquifer units could potentially also be exploited in future especially where shallow aquifers were brackish or saline. However, the study noted the risk of localised over-abstraction even if the overall level of groundwater exploitation for the province was low.
- *Maya Mountains* – There is insignificant amounts of groundwater, so water is taken from permanent streams and rainfall.
- *Toledo* – There is an apparent abundant supply of groundwater at shallow depths, with 2 major aquifers in the *Sepur* formation and the underlying *Campur limestone*.

Groundwater level are presently not monitored in Belize, unlike rivers where flow records of several decades exist and continue to be collected.

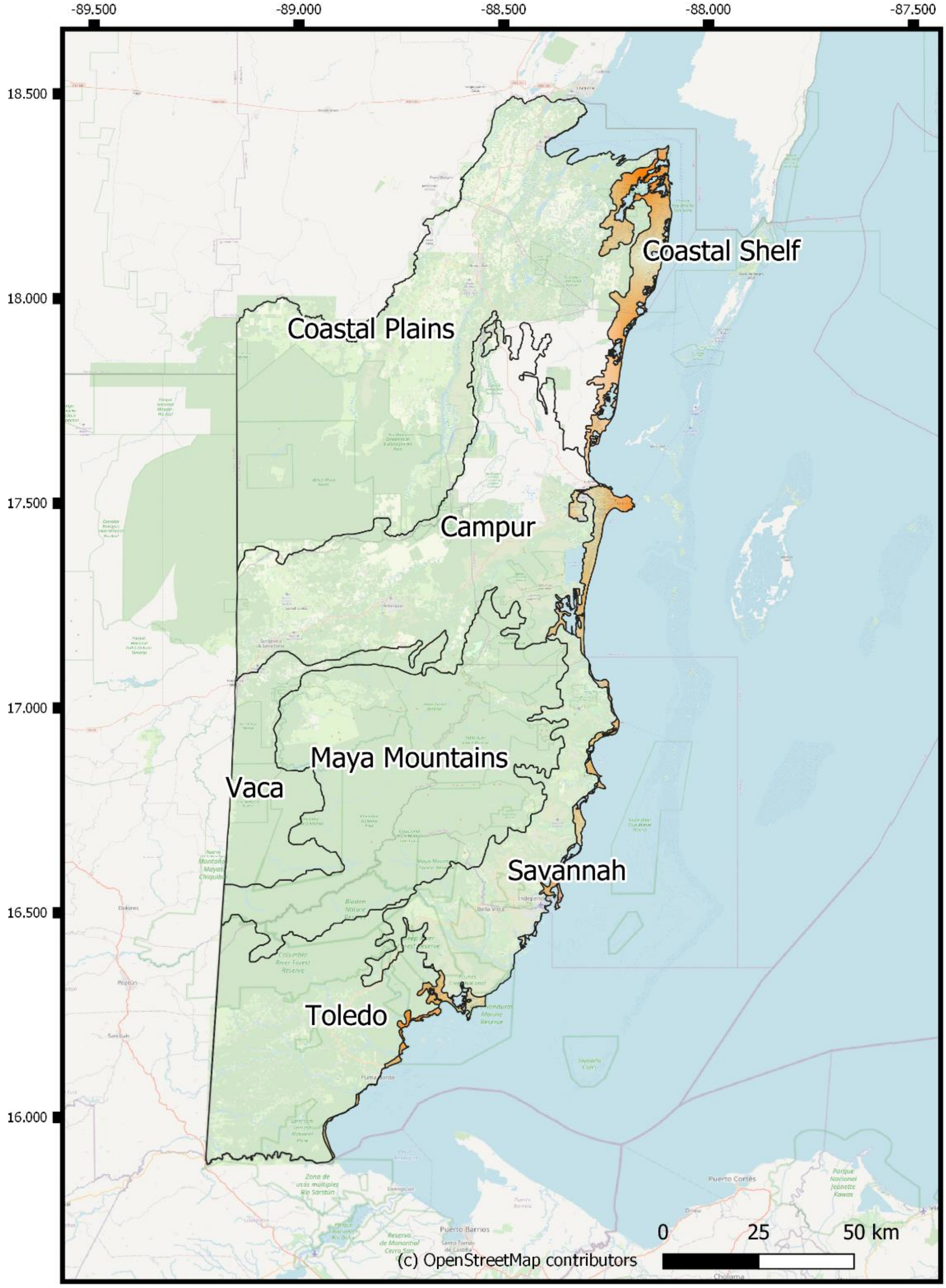

Figure 2.10: Belize groundwater provinces (Coastal Shelf province shaded for clarity) data provided by the NHS. Note that the Cayes are not included in the GIS

Some aquifers are transboundary (see Figure 2.11), although research is limited on the volumes of groundwater moving across national borders. Based on flow path analysis by UNESCO (2022) there is potential for groundwater flow from Mexico into Belize from aquifers in the Yucatan peninsula towards the Rio Hondo watershed in Belize. However, the volumes are not quantified. Given that the Rio Hondo forms the Mexico – Belize border is it likely that groundwater originating in Mexico and Belize contributes to river baseflow.

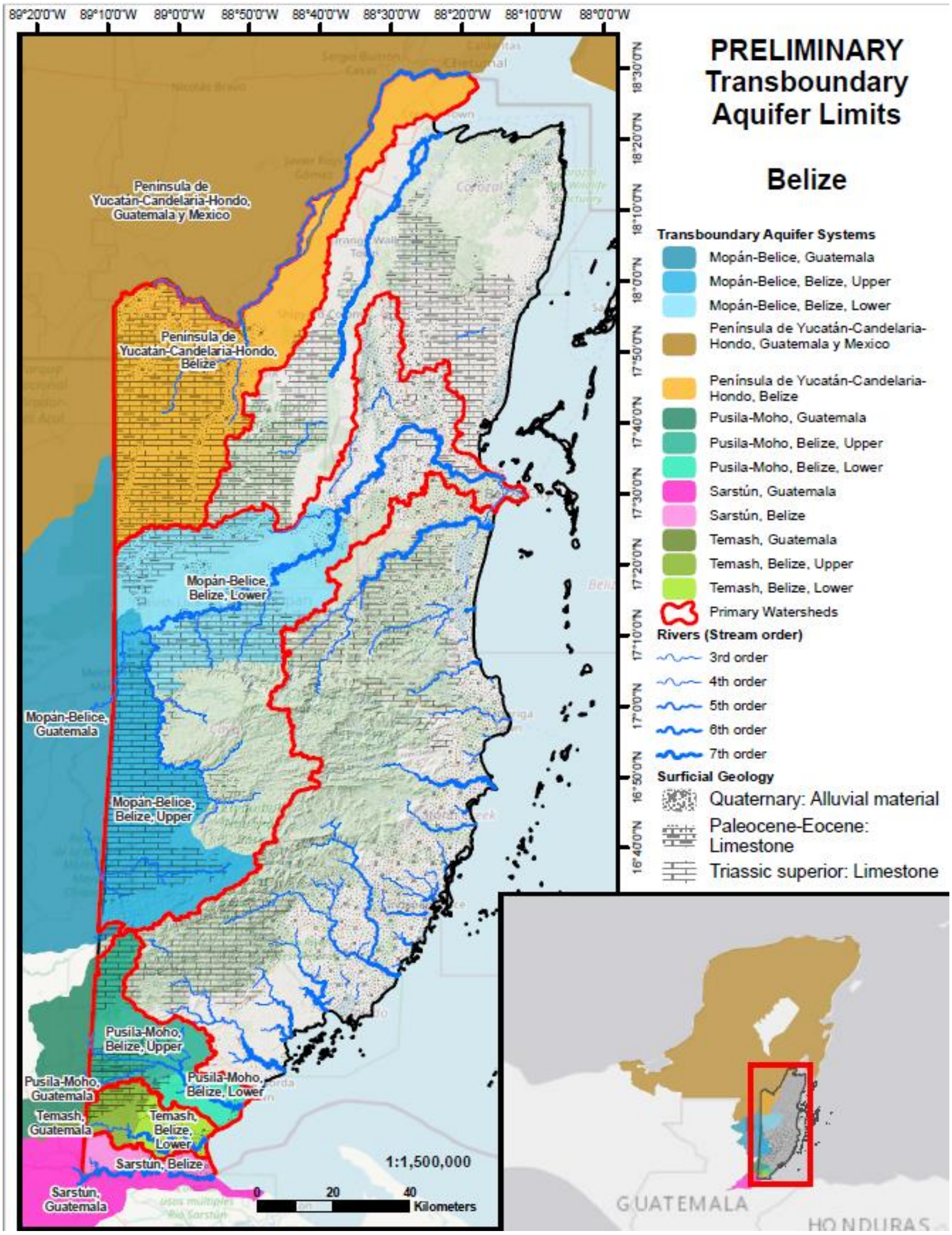

Figure 2.11: Preliminary map of transboundary aquifers in Belize (provided by the NHS)

2.4.2 Groundwater recharge

With the exception of the Maya mountains, Belize is characterised by a karst landscape with springs, sinkholes, and aquifer systems, from the dissolution of carbonate rock. Due to the karst hydrogeology, water rapidly flows underground to aquifers, which can lead to a lack of surface water and makes it more difficult to predict groundwater flow and recharge (Polk et al., 2013). Therefore, there is a strong link between surface and groundwater interactions.

Estimates of recharge in the Yucatan peninsula range from ~12% to 18% of rainfall (Edgar Rodríguez-Huerta et al, 2020), which may be broadly representative of the conditions in the northern districts of Belize, Orange Walk and Corozal where no estimates of recharge were available in the literature.

The Savannah Groundwater Study (UNDP, 2014) estimated recharge based on water balance and hydrograph separation techniques for the Savanah groundwater province. The study estimated rainfall at 73 l/s/km^2 and recharge to be around 15 to 20 l/s/km^2 (around 20-27% of rainfall) based on average conditions. The study concluded that only around 2% of natural recharge was being exploited in the province, offering further potential for development. It also noted that groundwater was being abstracted from shallow aquifers, and the significant potential resources in deeper aquifers could be explored and exploited if required.

Although groundwater exploitation is a small proportion of recharge overall, the potential for overexploitation locally should be considered, for example in coastal areas at risk of saline intrusion.

The link between groundwater and river flows is a key consideration in estimating groundwater recharge. In karstic systems, rivers are linked to aquifer systems and thus river flow characteristics may be impacted by changes in groundwater recharge and exploitation. However, groundwater and river flow monitoring with detailed linked groundwater and surface water modelling would be required to better understand these processes.

2.5 Previous studies

There have been very few studies on groundwater resources, although a broad classification of the groundwater provinces has been carried out by Hartshorn et al. (1984) as part of a wider Country Environmental Profile (CEP) of Belize. The report provides an overview on Belize's history, culture, and human resources; natural resources; and institutional and legal aspects of environmental issues. The natural resources section provides information on geology, hydrogeology, soil, minerals, and the coast.

A United Nations Development Report (UNDP, 2014) on 'Enhancing Belize's Resilience to Adapt to the Effects of Climate Change – Assessment of Belize's groundwater resources in the southern coastal water province referred to as the Savannah Groundwater Province' (UNDP, 2014) introduces the methodology applied for an assessment of Belize's groundwater resources in the Savannah Groundwater Province. The study involved acquiring existing data from data sets, reports and other publications, GIS processing, and groundwater mathematical modelling in the FEFLOW simulation package. Quantitative and qualitative groundwater assessments were then carried out. The study provides a set of raw data and their qualitative and quantitative interpretation on groundwater in the Savannah Province, which shows that the Savannah groundwater is most drained by rivers or directly into the Caribbean Sea. The model scenarios indicate that the utilisation of water in some areas is closer to resource limits.

A United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2022) study on the transboundary aquifer in the north of Belize, shared with Mexico and Guatemala aims to better understand the aquifers characteristics and the risks it is facing as it provides water for important agricultural areas in northern Belize. The study compiles information from the three countries on groundwater in addition to administrative, legal and institutional aspects; identifying knowledge gaps; and evaluating in a general and qualitative way, the state of groundwater governance in a transboundary aquifer. The flow from the aquifer is radial from central Mexico, but in general travels south to north influenced by hydraulic gradient, soil permeability, and rainfall. The study also discusses the vulnerability of groundwater in the aquifer, for example from increased water use and contamination from industry.

2.6 Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) has identified Belize as one of the countries most vulnerable to climate change due to the long, low-lying coastline, the 2nd longest barrier reef in the world, and many small islands that are prone to natural disasters (UNDP/ Geomedia Ltd, 2014). Belize is likely to be impacted by sea level rise, increased sea surface temperatures, changes in weather patterns and increased storm activity (UNDP/ Geomedia Ltd, 2014). There is predicted to be an increase in rainfall variability, seasonal evapotranspiration rates, and intense rainfall events and this will become more pronounced with climate change (CCCCC, 2015). Impacts could include fluctuations in surface water levels and quality which could lead to a decrease in the level and quality of groundwater and saline intrusions in coastal aquifers, where most of the population live (UNDP/ Geomedia Ltd, 2014).

Climate change projection data have been extracted from the World Bank Climate Change Knowledge Portal.[3] Climate projection data is modelled data from the global climate model compilations of the Coupled Model Inter-comparison Projects (CMIPs), overseen by the World Climate Research Program. Data presented is CMIP6, derived from the Sixth phase of the CMIPs. The CMIPs form the data foundation of the IPCC Assessment Reports and CMIP6 supports the IPCC's Sixth Assessment Report.

In addition, Belize's National Climate Change Policy, Strategy and Master Plan,[4] 2021 edition, contains climate change projections derived using a variety of statistical modelling approaches. Although these are not directly comparable to the CMIP6 model projections, they show the same direction and general trend, providing some further corroboration of the data presented here.

The key variables of interest with respect to long term sustainable groundwater management are the changes in seasonal and annual rainfall and temperature, both of which influence groundwater recharge. In addition, sea level rise poses a risk to coastal aquifers in Belize especially given the low lying topography of much of northern Belize where increasing sea levels have the potential to raise the saline-fresh groundwater interface, and to inundate low lying coastal lagoon areas with saline water.

Annual average precipitation shows a decline since 1950, however, the trend is not statistically significant (Figure 2.12). Mean annual temperatures have increased by 0.45°C since 1960 (World Bank, 2022) shown in Figure 2.13.

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[3] https://climateknowledgeportal.worldbank.org/country/belize (accessed 2nd May 2023)

[4] Belize's National Climate Change Policy, Strategy and Master Plan Belize. Ministry of Sustainable Development, Climate Change, and Disaster Risk Management, Belmopan, Belize, 2021

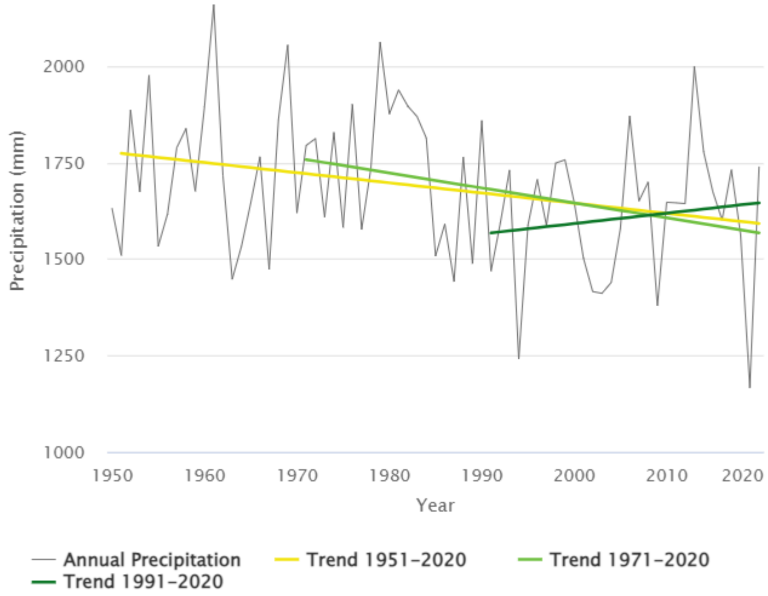

Figure 2.12: Observed annual precipitation (1950 to 2020) showing trends. Note none of these trends are statistically significant (World Bank, 2022)

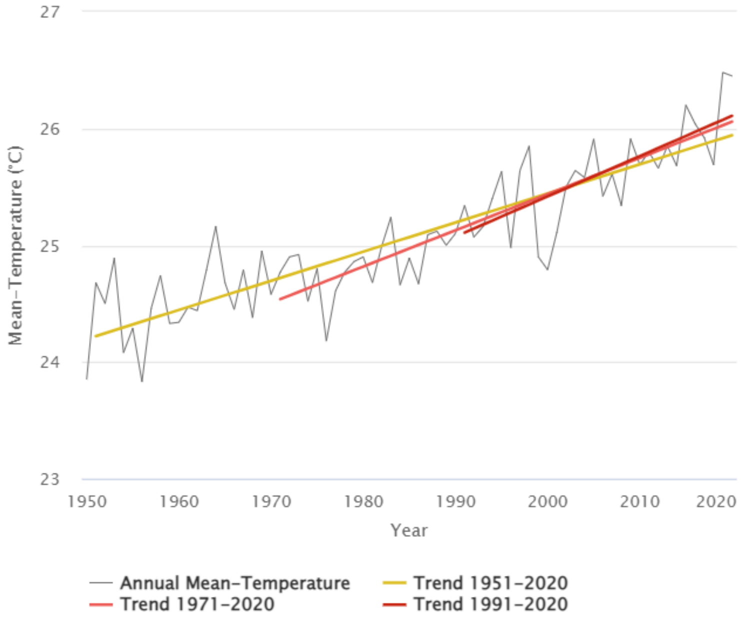

Figure 2.13: Observed annual average temperature (1950 to 2020) showing trends. (World Bank, 2022)

Climate change poses a compounding impact on water resources as a result of projected reduction in rainfall and rising temperatures impacting on river flows and groundwater resources.

Figure 2.14 shows the long-term projection for annual average rainfall under SSP2.6 and SSP8.5 which cover most of the range of climate change emissions uncertainty. Figure 2.15 shows the monthly projections expressed as percentage of the historical reference period. SSP2.6 indicates negligible changes in precipitation on average, whereas SSP8.5 indicates a much stronger trend towards a reduction in average rainfall to below 80% of reference period averages. If this emissions trajectory is followed, the reductions in rainfall are likely to increase the frequency and severity of drought events, reduce groundwater recharge, and increase crop water demands placing increasing pressure on groundwater resources. These projections are averaged across Belize as a whole, within Belize some variability in projections exists but this is small compared to the climate projection uncertainties and therefore Belize's average projections can be considered representative of subnational areas in Belize.

Figure 2.16 shows the long-term projections for annual average temperature in Belize under SSP2.6 and SSP8.5 which cover most of the range of climate change emissions uncertainty. Under RCP 2.6 the temperature stabilises at around 1˚C increase from the 1995-2014 baseline by the end of the century and under RCP 8.5 the temperature is 3.7˚C for the 2070-2099 epoch and rising.

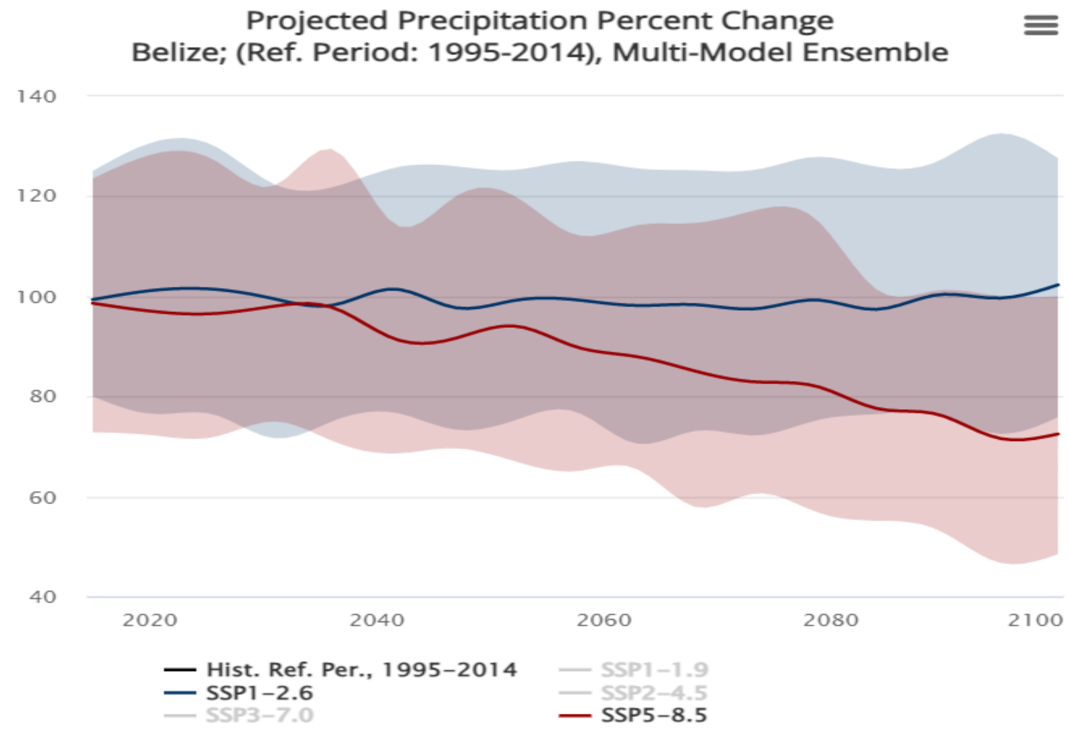

Figure 2.14: Projected Precipitation anomalies for 2020-2100 (Reference Period: 1995-2014), SSP1 – 2.6 & SSP5 – 8.5, Multi-Model Ensemble (100 on y axis indicates 100% of reference period average rainfall) (World Bank, 2022)

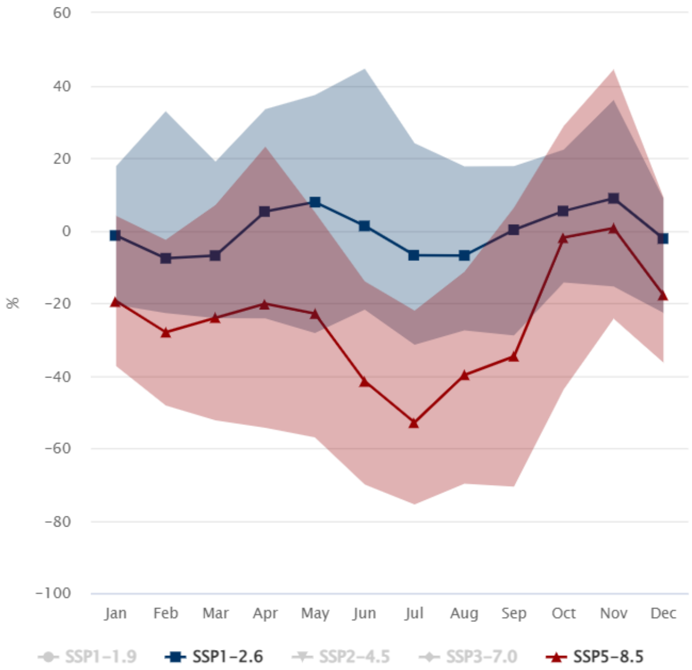

Figure 2.15: Projected monthly precipitation anomalies for the 2090s (Reference Period: 1995-2014), SSP1 – 2.6 & SSP5 – 8.5, Multi-Model Ensemble (0 on y axis indicates no change from reference period average rainfall) (World Bank, 2022)

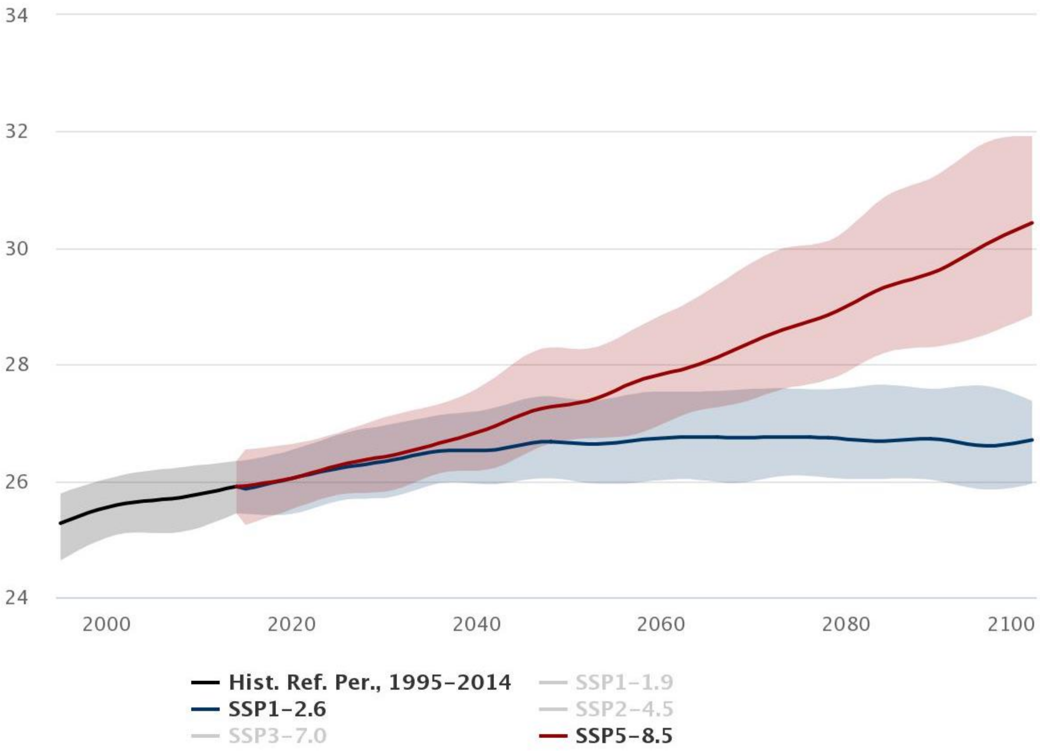

Figure 2.16: Projected Mean-Temperature for 2020-2100 (Reference Period: 1995-2014), SSP1-2.6 & SSP5-8.5, Multi- Model Ensemble (World Bank, 2022)

Figure 2.17 shows the projected sea level rise for coastal Belize, which ranges from around 45 cm under RCP 2.6 to over 70 cm under RCP 8.5 by the end of the century.

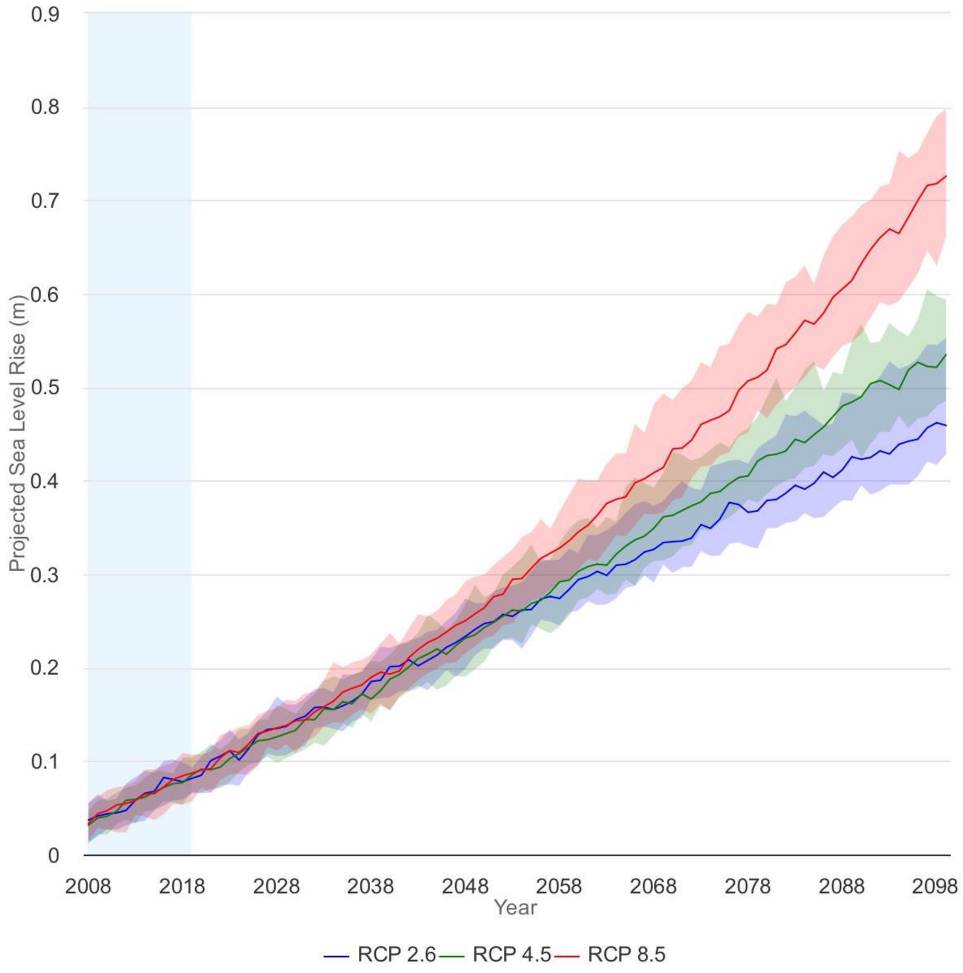

Figure 2.17: Belize sea level rise projections to 2098 for RCP 2.6, 4.5 and 8.5 (World Bank, 2022)

3 Groundwater consumption

3.1 Municipal and domestic consumption

Groundwater abstraction for municipal and domestic water consumption in Belize comprises groundwater wells operated by Belize Water Services, wells serving Rudimentary Water Systems (RWS) operated by village Water Boards and other private wells for domestic use.

BWS operates in licensed service areas, serving all the municipalities of the country as well as 44 villages. As at March 2020, BWS serves over 62,000 connections or approximately 270,000 consumers, with a total average water demand of approximately 230 million US gallons per month (BWS, Belize Water Services Limited Annual Report 2020, 2020).

Table 3.1 shows BWS water coverage in each district, which has been calculated as a function of the number of connections reported in the BWS 2020-2025 Business Plan (BWS, Belize Water Services Limited - Tariff Review and Business Plan 2020-2025, 2019) and the population estimated by the Statistical Institute of Belize for 2020 (SIB, 2021). Belize District is the only district where water is almost completely provided by BWS, together with Cayo, where BWS provides 74% of water. In the remaining districts the water coverage provided by BWS is 50% or less (Corozal, Orange Walk, Stann Creek, and Toledo).

The table provides BWS production rates by district based on BWS data for 2020. For the populations not served by BWS, the total water use has been estimated by multiplying population by a daily water use of 50 gallons per person per day. This is higher than the 34 gallons per person per day for BWS customers (based on BWS production rates and populations served) and may be conservative. However, households not served by BWS are likely to be on fixed rate tariffs in the case of RWS or to use private systems, and as such consumption may be higher. This figure could be refined if data on RWS system production is made available.

The total estimated municipal water use (BWS, RWS and private supplies) is around 6 billion gallons per year, or 23 million cubic metres per year in 2020.

Table 3.1: BWS water coverage in the different Belize districts as a function of the number of connections and population in each district

District	Population 2020	Household size	BWS Connections 2020	Estimated Population served by BWS	Estimated Population served by BWS (%)	BWS production 2020 (MG)	Assummed production rate for non BWS domestic systems (MG/year) (based on 50 gallons/person/ day)	Assumed total water production (MG/year) (BWS and non-BWS municipal supplies)	Type of BWS water source
Corozal	50,490	4.8	5370	25776	51	269	451	720	Groundwater
Orange Walk	53,373	4.8	5530	26544	50	260	490	750	Groundwater
Belize	127,683	3.8	33013	125449	98	1,706	41	1747	Mainly run of river / minor groundwater sources / wells in cayes
Cayo	102,115	4.5	16736	75312	74	883	489	1372	Groundwater and run of river
Stann Creek	46,015	4.1	4599	18856	41	273	496	769	Groundwater and run of river
Toledo	39,995	5.1	2627	13398	33	126	485	611	Groundwater
Total	**419,671**	**4.4**	**67,875**	**285,335**	**68**	**3,517**	**2,452**	**5,969**	

Figure 3.1 shows the historical and projected population for Belize up to 2100. Data to 2010 is based on census data from the Statistical Institute of Belize (SIB) and from 2010 to 2022 SIB estimates.[5] From 2022 onwards data from the United Nations, Department of Economic and Social

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[5] Statistical Institute of Belize https://sib.org.bz/statistics/population/

Affairs[6] has been used. The figure shows both the UN projections from 2010, as well the UN projections adjusted to match the SIB projections from 2022. Note that the SIB projections from 2010 to 2022 are steeper than the UN projections, and therefore may underestimate future population growth. Figure 3.2 shows the uncertainty associated with future projections.

Based on these projections a population of 600,000 by 2060 would be a reasonable estimate for strategic planning purposes. This represents a 36% population increase from 2022 to 2060, if per capita water use remains the same as the assumptions above this would equate to total municipal water demand rising from 6,000 million gallons per year to approximately 8,150 by 2060.

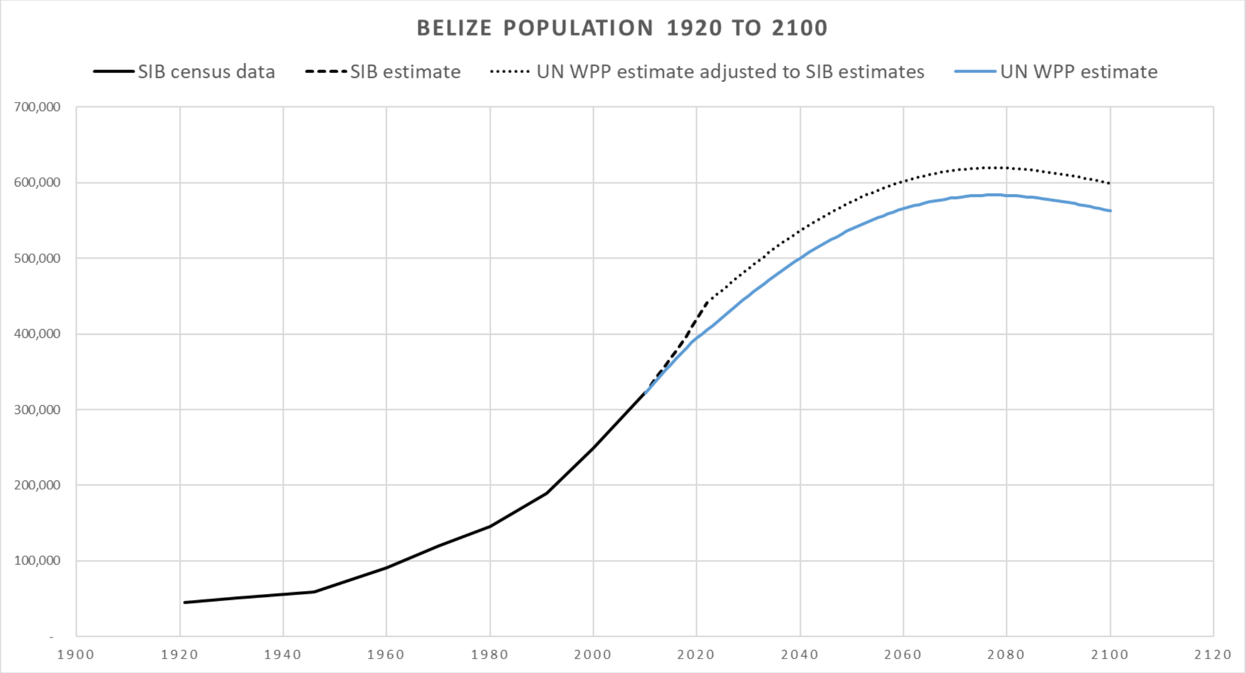

Figure 3.1: Belize population historical and projected to 2100

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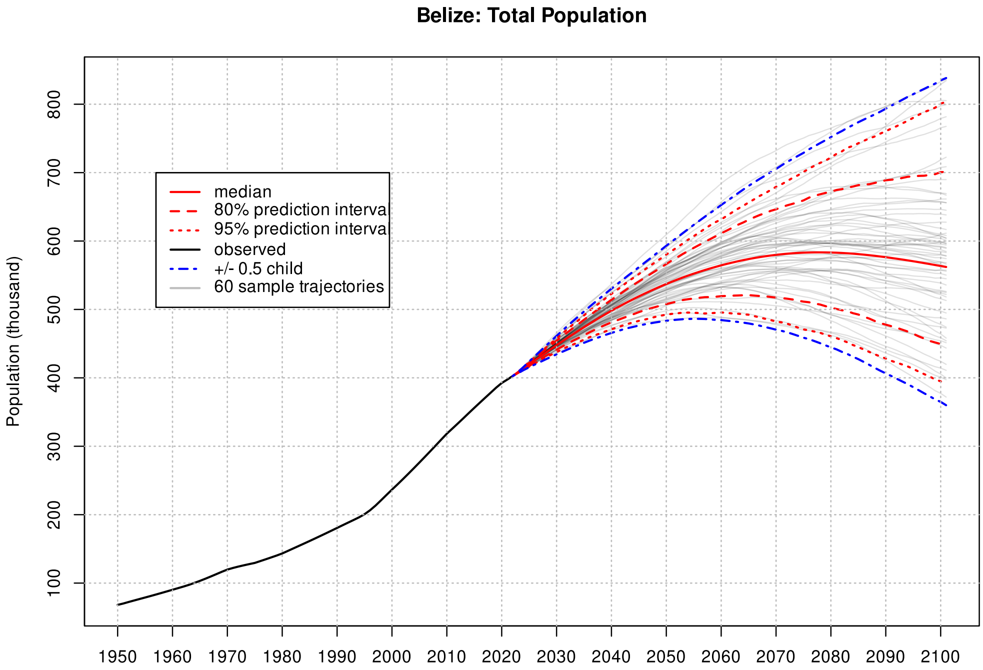
[6] United Nations, Department of Economic and Social Affairs, Population Division (2022). World Population Prospects: The 2022 Revision https://population.un.org/wpp/



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United Nations, DESA, Population Division. *World Population Prospects 2022*. http://population.un.org/wpp/

Figure 3.2: Probabilistic projections of population in Belize (UN-DESA)

Table 3.2 summarises the production rates for BWS systems. Sixty seven percent (67%) of the water supplied is produced using conventional water treatment processes with rivers as the extraction sources, 27% from groundwater and 6% from Reverse Osmosis (RO) plants. However, the use of river sources is focused only on Belize City, Belmopan, Dangriga, San Ignacio and Santa Elena. Many of the smaller systems rely on groundwater abstraction. Historically, BWS has mainly focused its activities in towns and cities. However, BWS has taken over supply systems in some rural areas and provides technical assistance to rural systems (BWS, Belize Water Services Limited - Tariff Review and Business Plan 2020-2025, 2019). If it is assumed that non-BWS water supplies depend solely on groundwater, then as a whole 57% of municipal demand is met through groundwater, a total of 3400 million gallons, or around 12.9 million cubic metres per year. Note that these figures are approximate and based on simple assumptions for non-BWS supplies.

Figure 3.3 shows a map of the main settlements and their populations, together with the BWS water supply system sources.

Table 3.2: Summary of water production for BWS water supply systems (data provided by BWS)

Region	Water sources	Water Treatment	Production in 2020 (Mgal and % of total production)
Mainland Coastal Systems			
Belize City	Surface water - intake Belize River and groundwater aquifer	Water treatment plant, filtration and chlorination facilities	1,439 Mgal, 40.9% of total production
Dangriga Town	Surface water - intake North Stann Creek River and ground water aquifer	Water treatment plant, filtration and chlorination facilities	150 Mgal, 4.3% of total production
Palencia Village	Groundwater aquifers - 2 wells	Pump station, chlorination facility	122 Mgal, 3.5% of total production

Region	Water sources	Water Treatment	Production in 2020 (Mgal and % of total production)
Punta Gorda Town	Groundwater aquifers – 3 wells	Pump station, chlorination facility	80 Mgal, 2.3% of total production
Corozal Town	Groundwater aquifers – 4 wells (one not in use)	Pump station, chlorination facility	269 Mgal, 7.7% of total production
Hattiville Village	Groundwater aquifers – 2 wells	Pump station, chlorination facility	47 Mgal, 1.3% of total production
Elridge/ Foresthome Village	Groundwater aquifers – 2 wells	Pump station, chlorination facility	46 Mgal, 1.3% of total production
Mainland Inland Systems			
Belmopan City	Surface water – intake Belize River and 4 groundwater aquifers	Water treatment plant, filtration and chlorination facilities	429 Mgal, 12.2% of total production
Benque Viejo Town	Groundwater aquifers – 2 wells – 1 spring	Pump station, chlorination facility	124 Mgal, 3.5% of total production
St Ignacio – St Elena Towns	Surface water – intake Macal River	Pump station, river bank infiltration, chlorination	330 Mgal, 9.4% of total production
Orange Walk Town	Groundwater aquifers – 5 wells	Pump station, chlorination facility	260 Mgal,7.4% of total production
Cayes Systems			
San Pedro Town	Caribbean Sea - 2 wells	Water Treatment plant, RO plant, and chlorination facilities	186 Mgal, 5.3% of total production
Caye Caulker Village	Caribbean Sea - 2 wells	Water treatment plant,RO plant and chlorination facilities	34 Mgal, 1% of total production

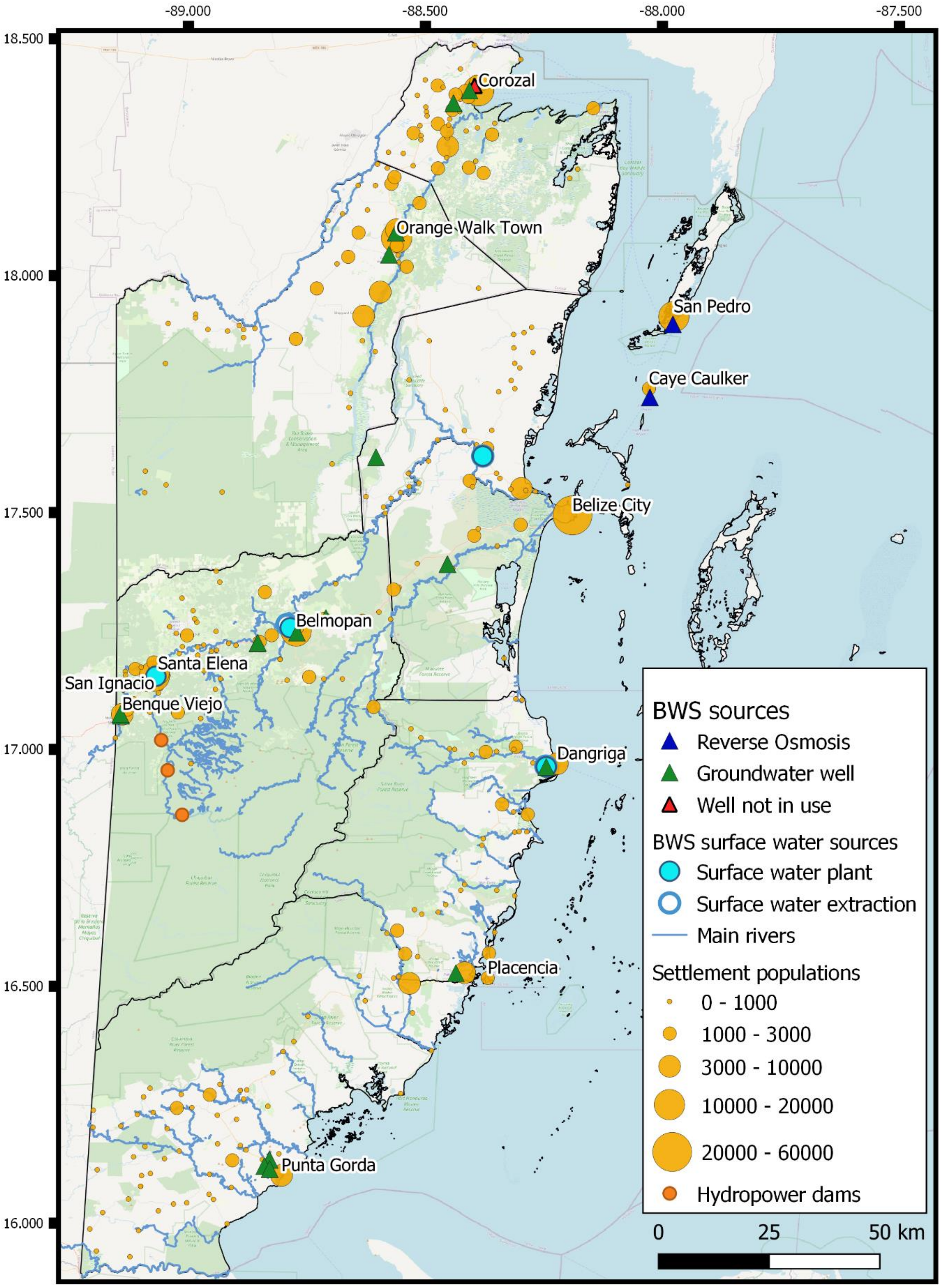


Figure 3.3: Map of Belize showing the main settlements and Belize Water Services (BWS) sources. OpenStreetMap background with settlement data from http://biological-diversity.info/GIS.htm and BWS source data provided by BWS

Rural Water Supply Services

There are 108 rural water supply systems serving 130 villages which are managed by a staff of 14 at the only Rural Water and Sanitation Unit within the Ministry of Rural Transformation, Community Development, Labour and Local Government (excluding the Village Water Boards, made up of volunteers). In addition, there are two drilling rigs operated by the Ministry of Rural Transformation for sinking boreholes for rural system expansion (Ministry of Rural Transformation, pers comm.).

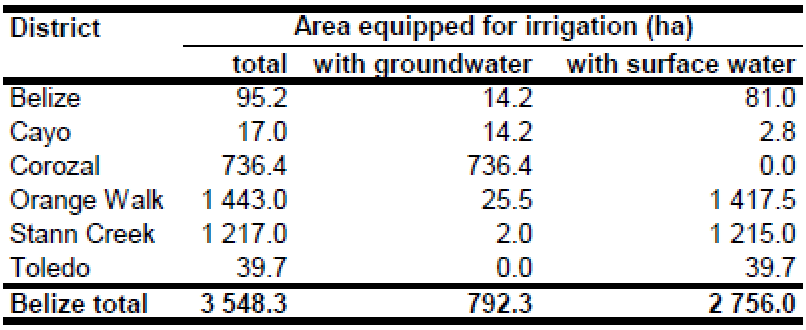
Rural water supply services face a myriad of challenges including a lack of financial viability, outdated tariff structure, lack of accountability, limited technical capacity and the physical remoteness of many of the villages served through these systems.

Tariffs for rural services vary, with approximately 50 Village Boards using flat rate tariffs, which disincentivises water conservation leading to excessive consumption of water and energy for pumping. Collection rates for customers is typically low, in some systems only 30 to 40% of bills are collected, with the average collection rate in 2012 of 63% (Ministry of Rural Transformation, pers comm.). These low rates were historically introduced to be affordable under poverty alleviation and basic services goals. However, they significantly limit the financial viability of rural supply services along with little knowledge of the importance of water conservation.

3.2 Agricultural consumption

Belize's agricultural water use based on the most recent estimates (2019) stands at 70 million cubic meters (1.85 billion gallons) annually – or approximately 68% of total water withdrawal as a share of internal resources based on FAO AQUSTAT data.[7] As it relates to the districts that are located within project area, Corozal and Orange Walk have approximately 2,200 ha. Of farmland under irrigation, which is 60% of all irrigated farmlands countrywide. Based on FAO data (see figure below), Corozal district contains most of the groundwater fed irrigation systems. These data are from 2005 and it is likely that irrigation has increased over the intervening period, based on the increasing agricultural development.

Table 3.3: Total irrigated farmland in Belize, 2005[8]



District	Area equipped for irrigation (ha)		
	total	with groundwater	with surface water
Belize	95.2	14.2	81.0
Cayo	17.0	14.2	2.8
Corozal	736.4	736.4	0.0
Orange Walk	1 443.0	25.5	1 417.5
Stann Creek	1 217.0	2.0	1 215.0
Toledo	39.7	0.0	39.7
Belize total	3 548.3	792.3	2 756.0

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[7] Source: https://www.fao.org/aquastat/en/databases/maindatabase/

[8] Source: https://www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas/irrigation-by-country/country/BLZ

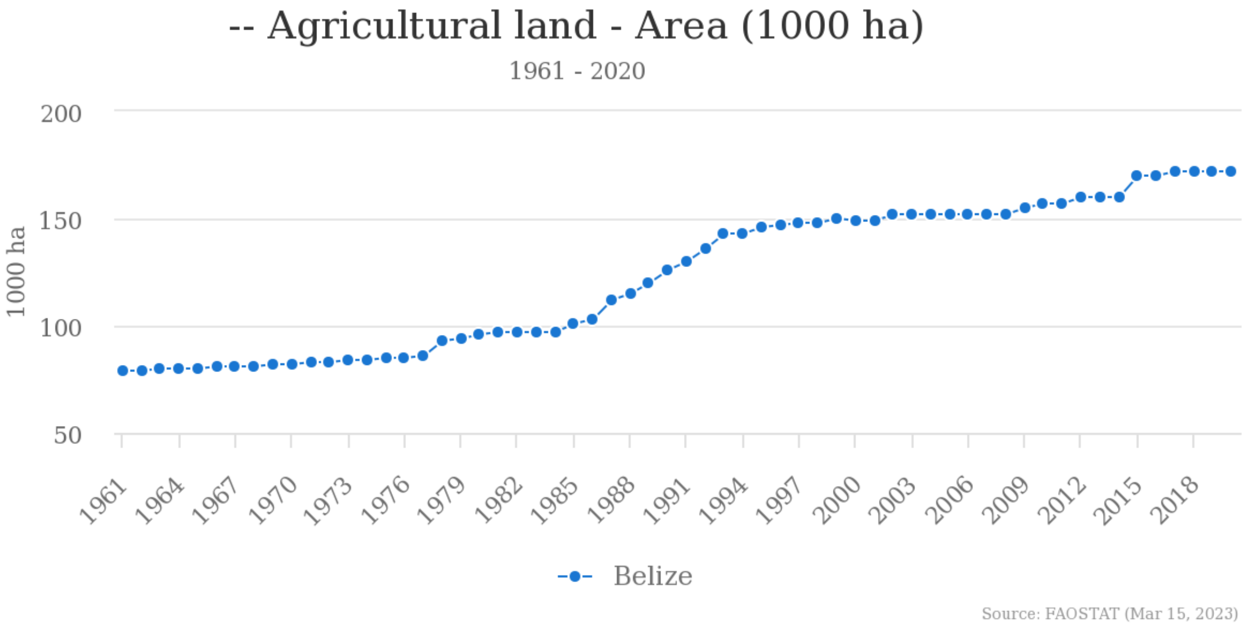

Figure 3.4: Total agricultural land area in Belize 1961-2020 (FAOSTAT)

According to the information provided by the Belize Agricultural Information Management System (BAIMS), there are currently 7,000 agricultural wells distributed amongst some 8,500 farms throughout both the Orange Walk and Corozal Districts. The farms in these districts cover a total of 130,000 ha. [320,000 ac.] of land, comprising a variety of commodities such as sugarcane, cattle, coconuts, onions, corn, beans, and other cash crops.

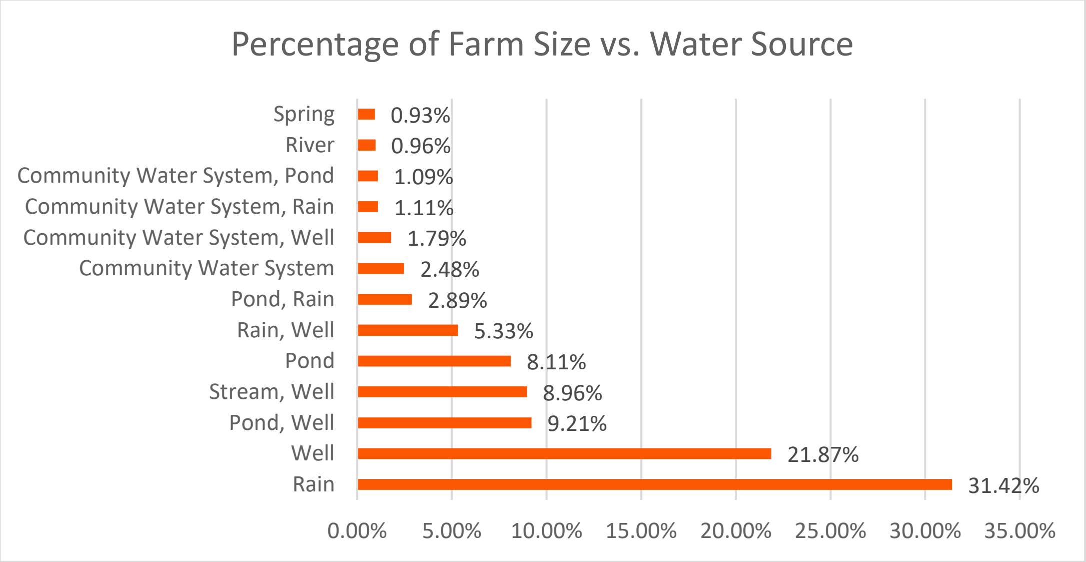

Figure 3.5: Percentage of farmland vs. Water
Source: BAIMS

Agriculture in Belize is at risk from weather fluctuations and climate hazards such as hurricanes, floods, and droughts. Climate change is likely to increase this risk, with predicted decreases in rainfall of up to 10% in some areas and increased variability in the distribution of rainfall, leading to more droughts and floods. Additionally, rising temperatures of 1.3 °C by the 2030s will negatively affect crops and livestock, resulting in changes in farming practices and potentially threatening food production (CCCCC. 2015). Decreasing rainfall is likely to lead to increased use of irrigation to maintain crop yields, although this has not been quantified, and would require further baseline data on current practices to permit a future projection of the impacts of climate change on irrigation water demand.

3.3 Industrial consumption

Aside from tourism and agriculture, the Belizean economy includes fishing, forestry, and manufacturing. Belize's fishing sector is significant, with key exports including shrimp, lobster, and conch. The forestry industry comprises lumber and furniture production, whereas manufacturing is dominated by the manufacture of food, drinks, and clothes. There are also small-scale companies that manufacture building materials, medical supplies, and textiles. Based on FAO data, Belize's industrial water use stands at 21 million cubic meters annually – or approximately 21% of total water withdrawal as a share of internal resources[9]. This data appears to date from 2000, and therefore may not be representative of the current situation. Globally, data on industrial water consumption are notably scarce (UN, 2022b) and Belize is no exception to this.

The Belize Sugar Industry (BSI) factory is the single largest industrial complex within the project area. This facility is located along banks of the New River, some 2 km south of Orange Walk Town. The BSI facility contains a sugar mill with a crushing capacity of 1.3 million tons of sugarcane per year and an average daily milling capacity of 6,800 tons. There is also a 31.5-megawatt ("MW") cogeneration energy power plant, the Belize Co-Generation Energy Limited ("BELCOGEN") facility, located adjacent to the sugar mill and powers the Company's milling activities. BELCOGEN exports power to the national public grid, supplying roughly 15% of Belize's energy needs. BSI has 10 groundwater abstraction licenses and 8 surface water abstraction licenses. The Company presently owns two wells at Chan Pine Ridge, one of which is not in operation. Flow meters were put in the wells, and a log is maintained on a regular basis by the company (IADB, 2021).

There is also a new beer brewing company in operation in the project area – Caribbean International Brewery Company (CIB). They manufacture bottled water, as well as flavoured carbonated beverages and beers for both the domestic and export markets in Belize.

Other large industrial users of ground water in the project area include poultry processing plants and a construction company. The table below provides information of the annual total usage for the major industries in the New River area based on data provided by the National Hydrological Service. Note that these are unlikely to be exhaustive, as it is understood that the requirement for abstraction licences for industrial water use, and the reporting of actual abstraction data, are not enforced and there may be a large number of additional industrial users.

Table 3.4: record of all industrial abstractions for 2022

Industry	Town/Village	Purpose	Total (US Gal.)	Total (m³)	% of Total
Caribbean International Brewery Company Ltd	Carmelita Village	Industrial	487,434	1,845	0.65%
BSI/ ASR	Chan Pine Ridge	Industrial	61,759,398	233,785	82.10%
Caribbean Chicken	Blue Creek Village	Processing	12,724,529	48,168	16.92%
Overseas Engineering & Construction Co.	Chunnox Village	Domestic	251,972	954	0.33%
		Total	75,223,334	284,751	

Source: National Hydrological Service

Note: all sources are drilled wells

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[9] FAO. 2015. AQUASTAT Country Profile – Belize. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy

3.4 Total Water Consumption

Water is used in various sectors such as residential, industrial, and agricultural as discussed above. Each of these sectors has different patterns of water usage, with varying levels of consumption and impact on the environment. Residential water usage refers to the water consumed by households for domestic purposes such as drinking, cooking, cleaning, and bathing, while industrial water usage includes the water consumed in manufacturing processes and other industrial applications. At a national level the domestic, agricultural and industrial demand are summarised below.

Based on BWS data and assumed per capita water demand for those persons not served by BWS, municipal and domestic water demand is estimated to be 23 million m^3/year (6,000 million gallons per year). It is estimated that 57% of this total is served from groundwater sources, 40% from rivers and 3% from reverse osmosis on the Cayes. Based on a population increase of 36% from 2022 to 2060, this would rise to 31 million m^3/year by 2060 (8,150 million gallons per year).

Agricultural water demand based on FAO data is estimated to be in the region of 70 million m^3/year (1.85 billion gallons per year). This information dates from 2000 and it is likely that agricultural water consumption has increased over the intervening period as a result of increasing land conversion to agriculture. An updated estimate of agricultural water demand is urgently required in order to better understand its impacts on water resources.

Industrial water consumption at national level is 21 million m^3/year (5,500 million gallons per year) – or approximately 21% of total water withdrawal as a share of internal resources (based on FAO Aquastat data). This data appears to date from 2000, and therefore may not be representative of the current situation. Actual abstraction volumes for industries in the New River area for 2022 total 284,000 m^3 and are likely a substantial underestimate of the true figure. Mandatory water abstraction licencing and submission of actual abstraction volumes is recommended to increase confidence in the data, for both consumptive and non-consumptive uses.

4 Groundwater management and exploitation in Belize

4.1 Groundwater management

Water is crucial to the sustenance of life and its importance to human, social and economic development cannot be overstated. The competing demand for water by industry, agriculture, and tourism, as well as the role that water plays in the preservation of biodiversity, ecosystems, and human health, mandates the need for a coordinated, cohesive, and holistic approach to the management of water resources. The need for integrated water resources management, policy and good governance is further heightened by the threat to the availability of the resource owing to the negative impacts of climate change, inefficient resource use, and pollution.

Legal Framework for Water Resources Management

A robust water governance and management framework is required to ensure resource protection, the integrity of supply distribution, equity, and protection for vulnerable groups, and to manage cross sectoral and transboundary conflicts.

Belize has embraced the guiding principles of the IWRM concept through the adoption of a National Integrated Water Resources Management Policy (including Climate Change) for Belize, 2008 which is centred on the achievement of the equitable and sustainable use of the resource. In order to achieve these goals, IWRM guidelines prescribe a multi-sectoral, fully inclusive and participatory approach to the management of the resource by all stakeholders – public, private and community; as well as the enactment of policies and legislation that limit environmental degradation and encourage efficiency in the use of the resource. The management of water resources in Belize however continues to remain fragmented.

The key pieces of legislation which govern the safe and sustainable supply of potable water in Belize are:

The Belize Water Industry Act Chapter 222 Revised 2020

This act provides for the following:

- The provision of authority to the Belize Public Utilities Commission (PUC) for the regulation of the water sector including inter alia the authorization of licensees to approved providers of water supply and sewerage services; the determination of charges, tariffs, and fees for the provision of water supply and sewerage services; the enforcement of penalties for breaches of service standards.
- Appointment of the Minister of Natural Resources to discharge such duties that promote the conservation of water and preservation and protection of water resources in Belize.

The Belize Public Utilities Commission Act Chapter 223 Revised 2000

This piece of legislation provides for the establishment of the Belize Public Utilities Commission and the articulation of its functions as it relates to the regulation of the water, energy, and telecommunications sectors in Belize. The Belize Water Services Limited is the primary water and wastewater service provider licensed by the PUC. The company provides service to all urban and contiguous villages in Belize.

Belize Village Councils Act Chapter 88, Revised 2020

The Village Councils Act makes provision under Part VII of the Act for the creation of Village Water Boards that are responsible for overseeing the operations and maintenance of rural water supply systems. This includes the regulation of pumping hours, the expansion of pipes and other infrastructure, the collection of fees and the enforcement of disconnection measures for defaulting customers.

Belize National Integrated Water Resources Act Chapter 222.01

This act provides for the establishment of the National Integrated Water Resource Authority and the vesting within it *inter alia* the control and protection of groundwater and well drilling; the control of water abstraction and pollution control.

The Environmental Protection Act Chapter 328 of the Substantive Laws of Belize

This Act vests powers of environmental enforcement to the Chief Environmental Officer within the Department of the Environment to ensure the preservation and conservation and sustainable use of Belize's natural resources.

Institutional Roles and Responsibilities

Key institutional roles in the management of Belize's water sector is summarised in Table 4.1. It does not include the National Integrated Water Resource Authority as at the time of writing as the structure has not been established. this has not been implemented.

Table 4.1: Summary of institutional roles and responsibilities in the Belize water sector

Agency	Reporting Responsibility/Line Ministry	Mandate
The National Hydrological Service	The Ministry of Natural Resources	The sustainable Management of all of Belize's Freshwater Resources
National Climate Change Office	Ministry of Economic Development Belize National Climate Change Committee comprising various Ministries	Coordination of Belize's climate change policies and actions
The Department of the Environment	Ministry of Sustainable Development, Climate Change and Disaster Risk Management	To carry out regulatory enforcement responsibilities under the Environmental Protection Act Chapter 328 of

Agency	Reporting Responsibility/Line Ministry	Mandate
		the Substantive laws of Belize and other relevant pieces of environmental legislation and to recommend national policies that promote improvements in environmental quality
Belize Public Utilities Commission	Ministry of Public Utilities	To regulate the sectors of Water, Electricity & Telecommunications under the Public Utilities Commission Substantive Act Chapter 223 Revised edition 2020
Belize Water Services Limited	Public Utilities Commission	National Water and Sewerage service provider. It operates as a regulated utility under the Water Industry Act 2001
Village Water Boards	Village Water Councils Ministry of Rural Transformation, Community Development, Labour and Local Government – Rural Water Supply and Sanitation Unit	Rural supply of potable water
Department of Public Health	Ministry of Health and Wellness	Responsible for the Quality of Water supplied under the Water Industry Act 2001

Financing

Funding for the water sector in Belize stems from 3 sources:

- Tariffs paid by local consumers (industry and households) for amounts consumed;
- Government tax revenue from other sectors that are diverted into the water sector for water and wastewater infrastructure improvements and projects;
- Grant and Loan Funding from the International Donor Community and International Funding Institutions, notably through the Belize Social Investment Fund (BSIF), which provides a mechanism for facilitating investment in projects including water and sanitation.

Tariffs charged by Belize Water Services Limited are regulated by the Public Utilities Commission. The tariff structure is reviewed in 5-year cycles and is designed with the objectives of conservation, equity, affordability, and financial viability of the service provider.

The costs of operating rudimentary water systems are borne by village councils and vary considerably between rural districts. Village Councils therefore are empowered under the Act to set the rates for rural water supply to cover the costs of operations, infrastructure maintenance and expansion. These rates are therefore non uniform and reflective of the local context, but do not necessarily reflect full cost recovery for service provision.

4.2 Transboundary issues

Transboundary issues refer to the challenges that arise when water resources, such as rivers, lakes, and aquifers cross national borders. These issues can be particularly challenging when it comes to groundwater, as it is often difficult to monitor and manage due to its subterranean nature.

One of the main transboundary issues related to groundwater is the management and allocation of shared aquifers. Many countries share aquifers, and disputes can arise over the use and management of these resources. For example, a country may extract more water from an aquifer than it can sustainably recharge, which can lead to depletion and lower water levels for downstream users.

Another transboundary issue related to groundwater is the potential for pollution to cross national borders. Pollution from one country can migrate into the groundwater of neighbouring countries and affect the quality of the water. This can be particularly challenging when the source of the pollution is difficult to identify or locate, or when different countries have different regulations and standards for groundwater quality.

Climate change is also a transboundary issue as it can lead to changes in precipitation and temperature patterns, which can affect the recharge of aquifers and the availability of water for irrigation. This can lead to disputes over the allocation of water resources and the management of aquifers.

One of the main transboundary water issues in Belize is related to the management and allocation of shared aquifers – specifically with Mexico and Guatemala. For this project, the main transboundary aquifer in question is the *Yucatan Peninsula-Candelaria-Hondo* aquifer. This unconfined aquifer underlies much of the Yucatan peninsula, however only 2% by area is within Belize's territory. The aquifer's geology is best described as being comprised of mostly limestone rock with several major fracture lines running in the north-south direction – particularly close to the project area of northwest Orange Walk.

Due to the solubility of limestone, the general flow path of groundwater is difficult to predict in karstic situations but is believed to be generally radial from the centre of the peninsular. As such, it is therefore reasonable to assume that transboundary groundwater flow is going in a southeast direction. Also note that this property of limestone allows for the formation of small-scale fractures that become a part of an effective hydraulic underground conduit system.

Where the national border is defined by a river such as the Rio Hondo between northern Belize and Mexico, the river is likely to intercept shallow groundwater flowing south-east from Mexico and discharge this flow into the river as baseflow.

The natural water quality of the aquifer varies greatly from saline (sodium chloride) conditions dominant in coastal regions, hard water (calcium bicarbonate) in the central areas and calcium sulphate water in a small portion of the south-central section of the aquifer.

The aquifer is vulnerable to pollution from a number of sources – the main ones being farming and livestock activities as well as runoff from wastewater and landfill. This vulnerability is intensified due to an increase in deforestation (leading to less recharge) and climate change (lower rainfall amounts).

Being aware of these factors, the existence of high transmissivity pathways and the potential pollution activities, underscores the importance of having an effective groundwater monitoring system that will be able to detect threats to the aquifer system on Belize's side of the transboundary.

4.3 Groundwater quality

4.3.1 Overview of groundwater quality issues

The physical, chemical, and biological qualities of groundwater are referred to as groundwater quality. It is significant because it decides whether groundwater is suitable for different applications such as drinking, irrigation, and industrial reasons. Poor groundwater quality has profound effects on human health, the environment, and economic growth. Bacteria, viruses, herbicides, fertilizers, and industrial pollutants can all cause health issues if taken in high enough amounts. Poor groundwater quality may also be harmful to wildlife and ecosystems. Furthermore, it has the potential to restrict the use of groundwater as a water resource, hurting agriculture and other businesses that rely on it.[10]

Groundwater is water that has infiltrated through soil and rock, which removes impurities and filters the water over time. This results in water that is typically free of harmful microorganisms, making it a desirable source of water for human consumption. However, the ease of access to this resource also increases the risk of overuse. Though groundwater is generally less susceptible to pollution than surface water, it may contain high levels of dissolved minerals from the rock it has flowed through.[11]

Groundwater contamination is distinct from surface water contamination as it is not easily visible, and the recovery of the resource is challenging with current technology. Contaminants in groundwater often lack colour and smell, making it hard to detect. Additionally, the effects of contaminated groundwater on human health can be long-term and difficult to identify. Cleaning up contaminated groundwater is difficult and expensive as it is located deep underground and can take a long time to purify, even if the source of contamination is removed.[12]

Examples of physical characteristics of groundwater include:

- Groundwater temperature varies based on location and depth. Groundwater is often colder than surface water;
- Depending on the amount of dissolved minerals or sediment, the color of groundwater can range from clear to varied colors of brown or gray;
- Turbidity is a measure of the amount of suspended particles in water that can be created by silt, dissolved minerals, or other particles;
- Odor may be created by dissolved gases like sulfur, as well as bacteria and other microbes.

Examples of chemical characteristics of groundwater include:

- The pH of groundwater varies based on geology and the presence of dissolved minerals. A pH of 7 is considered neutral for most applications, but it can be slightly acidic or alkaline;
- Dissolved oxygen is critical for aquatic creature viability and can be influenced by pollution or temperature changes;
- Conductivity is a measurement of water's capacity to conduct electricity and may be used to detect the presence of dissolved minerals or contaminants;
- The presence of dissolved minerals such as calcium, magnesium, or iron in groundwater can impact its taste, odor, and appropriateness for various purposes.

Examples of biological characteristics of groundwater include:

- The presence of microorganisms such as bacteria or viruses might indicate pollution or inadequate sanitation procedures;
- The appearance of algae might suggest the presence of excessive fertilizers or warm temperatures;
- The presence of small water organisms like worms or insects might indicate the presence of a healthy environment.

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[10] WHO Publication: Protecting ground water for health, 2006

[11] UNEP Publication: Groundwater: a threatened resource, 1996

[12] Peiyue Li, Sources and Consequences of Groundwater Contamination, 2020

Health effects of poor groundwater quality

Poor groundwater quality can have significant health implications for those who rely on it for drinking and other household uses. Several of the health risks associated with poor groundwater quality include:

- Groundwater may be polluted with a wide range of chemicals and contaminants, including pesticides, fertilizers, heavy metals, and industrial waste. These toxins have the potential to cause major health problems, such as cancer, brain impairment, and developmental and reproductive issues.
- Bacterial and viral contamination: Poorly designed or poorly maintained wells can allow bacteria and viruses to pollute groundwater, resulting in deadly infections such as typhoid fever, cholera, and E. coli.
- Lack of access to safe drinking water: When groundwater is contaminated, people may not have access to safe drinking water, which can lead to dehydration and a range of health problems.

Environmental Impacts of poor groundwater quality

Poor groundwater quality can have significant environmental impacts, both locally and globally. Some of the most significant impacts include:

- **Loss of biodiversity:** A variety of plant and animal species depend on groundwater for vital habitat and supplies. These species are susceptible to injury or extinction due to groundwater contamination, which reduces biodiversity.
- **Ecosystem damage:** Groundwater is essential for sustaining the health of ecosystems since it supports plant and animal growth and helps control stream flows. These procedures can be hampered by groundwater contamination, which will result in a reduction in the ecosystem's health.
- **Loss of agricultural productivity:** Contamination of groundwater, a key supply of irrigation water for agriculture, can render it hazardous for use in irrigation, resulting in a reduction in agricultural output.
- **Economic effects:** Industries that depend on groundwater, such agriculture, mining, and manufacturing, may experience employment losses and a decline in economic activity because of contamination of the groundwater. Due to the negative effects that polluted water has on human health, it may also result in higher healthcare bills.
- **Human health impacts:** As mentioned, poor groundwater quality can have significant health impacts on people who rely on it for drinking and other household uses.

4.3.2 Groundwater quality data collection

The number of locations and frequency of groundwater sampling depend on the specific goals of the investigation and the characteristics of the study area. In general, larger, and more frequent sampling may be needed for sites with a known or suspected contamination, or for sites that are being monitored for compliance with regulations. In Belize, explicit groundwater sampling activities is essentially non-existent, other than as part of drinking water compliance.

However, various entities execute water quality testing as a part of their regulatory procedures. These include the Belize Water Services Limited (BWSL) and the Water Laboratory Unit housed by the Ministry of Health and Wellness.

Ministry of Health and Wellness testing

The Ministry of Health and Wellness (MoHW) executes this legal authority through a national drinking water quality monitoring programme under which water samples are collected from:

- Belize Water Services Systems (BWS);
- Rudimentary Water Systems (RWS);

- Bottled water companies;
- Handpumps;
- Any other drinking water source.

For these routine tests, drinking water samples are collected by the Public Health Inspectors and sent to the National Water Quality Laboratory in Belize City for testing. Samples are tested for bacteriological and chemical parameters. The monitoring frequency is provided below:

Table 4.2: Water Quality Monitoring Frequency (MoHW)

	Frequency of testing		
Water Source	**Monthly**	**Quarterly**	**Yearly**
Urban Water Systems	X		
Rudimentary Water Systems		X	
Bottled Water Companies	X		
Hand pumps			X
Other Sources	As required/requested		

4.3.3 Groundwater quality: New River Catchment

The following data provides water quality test results provided by the Ministry of Health, of water sources found in various locations in the Orange Walk and Corozal districts. For chemical analysis, the water quality parameters measured are Alkalinity, Sulphate, pH, Turbidity, Salinity, Chlorides, Hardness, Conductivity, Nitrate Nitrogen, Iron, and Total Dissolved Solids (TDS). For bacteriological analysis, tests performed on the water samples include free chlorine, total coliform, faecal coliform, and E. coli.

Water samples were collected and analysed from the villages of Indian Church, Carmelita, Tower Hill, San Jose Nuevo Palmar, San Estevan, and Santa Cruz in the Orange Walk District. As well as the villages of Caledonia, Estrella, Libertad, and Concepcion in the Corozal district. The following table shows the average of the various parameters.

While the data provide a general indication of groundwater quality in these communities for the purpose of drinking water quality surveillance, they do not provide the continuity or frequency of records required for understanding the long-term trends, or intra-annual variability of environmental groundwater quality.

Table 4.3: Average of water test results for each parameter. Note that all units are in mg/l except for pH and conductivity in µS/cm

Village	Alkalinity	Sulfate	pH	Turbidity	Salinity	Chlorides	Hardness	Conductivity	Nitrate	Iron	TDS	Comment
Indian Church	338.33	120.33	7.26	1.04	3.80	7.34	363.33	894.00	2.67	0.05	446.67	3 data points collected between May 2009 and April 2016
Carmelita/ Tower Hill	295.57	340.29	7.05	0.44	0.81	50.80	636.71	1325.86	1.34	0.08	656.46	7 data points collected between Sept 2009 and July 2022
San Estevan	315.89	125.33	7.14	3.04	0.61	34.38	377.56	1017.44	4.49	0.04	505.16	9 data points collected between June 2014 and Oct. 2022
Santa Cruz	316.60	195.32	7.15	1.51	1.74	30.84	459.20	1079.10	2.83	0.06	536.09	3 data points collected between June 2009 and April 2013
Libertad and Concepcion	309.35	220.31	7.11	1.66	N/a	38.67	491.16	1140.80	2.89	0.06	565.90	8 data points collected between Feb. 2014 and Nov. 2019

The hardness values in the table appear to be on the higher side. The hardness of the water in Indian Church, Santa Cruz, Libertad, and Concepcion are all above 300 mg/L, with Libertad and Concepcion having the highest hardness at 491.16 mg/L. These values indicate that the water in these villages is hard, which can affect the performance of soap and detergents, as well as cause build up in pipes. In the table, the conductivity values for each village range from 894.00 to 1325.86 µS/cm, with Carmelita/Tower Hill having the highest conductivity. The TDS values range from 446.67 to 656.46 mg/L, with Carmelita/Tower Hill again having the highest value. These values indicate that the water in these villages has a relatively high level of inorganic salts, which can impact the taste, smell, and overall quality of the water.

Belize Water Services Limited

BWSL has a regulatory mandate to routinely test their treated and untreated water for all their operations countrywide. Since groundwater is their current and only water source for the Orange Walk and Corozal operations, the test results provided will give a good indication of the groundwater quality of that area. In 2022, BWSL supplied its customers in Orange Walk and Corozal with approximately 272 million and 262 million gallons of potable water respectively. Belize Water Services Limited (BWS) provided the project with some water quality test results for its operations in the Northern part of the country. The data received was for its abstraction wells in Calcutta and San Andres for Corozal Town and the Clarke Street wells for Orange Walk Town. Test results received from BWSL shows similar parameter ranges as stated in Table 4.3 above.

Other Recent Studies

The study conducted by Husaini (2020) published in the Journal of Health & Pollution entitled *Nitrate Levels in Rural Drinking Water in Belize*, 2020, had as its goal to determine the levels of nitrates in rural drinking water sources in Belize and assess their safety for both human and animal consumption. Additionally, it aimed to establish a baseline for monitoring nitrate concentrations to avoid potential public health risks. Water samples were collected from 40 villages in Belize, including 43 samples from reservoirs, wells, vats, and standpipes, and were analysed for nitrates using the cadmium reduction method.

The results showed that most of the water samples analysed, except for four (4) from four separate locations, had nitrate levels below 10 mg/L.[13] A few samples from the northern region of the country had levels above 10 mg/L, likely due to agricultural activities in those areas, see Figure 4.1. Note that the four previously mentioned sites with nitrate concentration higher than 10mg/l are either in or close to the New River catchment basin.

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[13] Maximum acceptable limit for Nitrates in drinking water: https://www.epa.gov/ground-water-anddrinking-water/national-primary-drinking-waterregulations#Inorganic

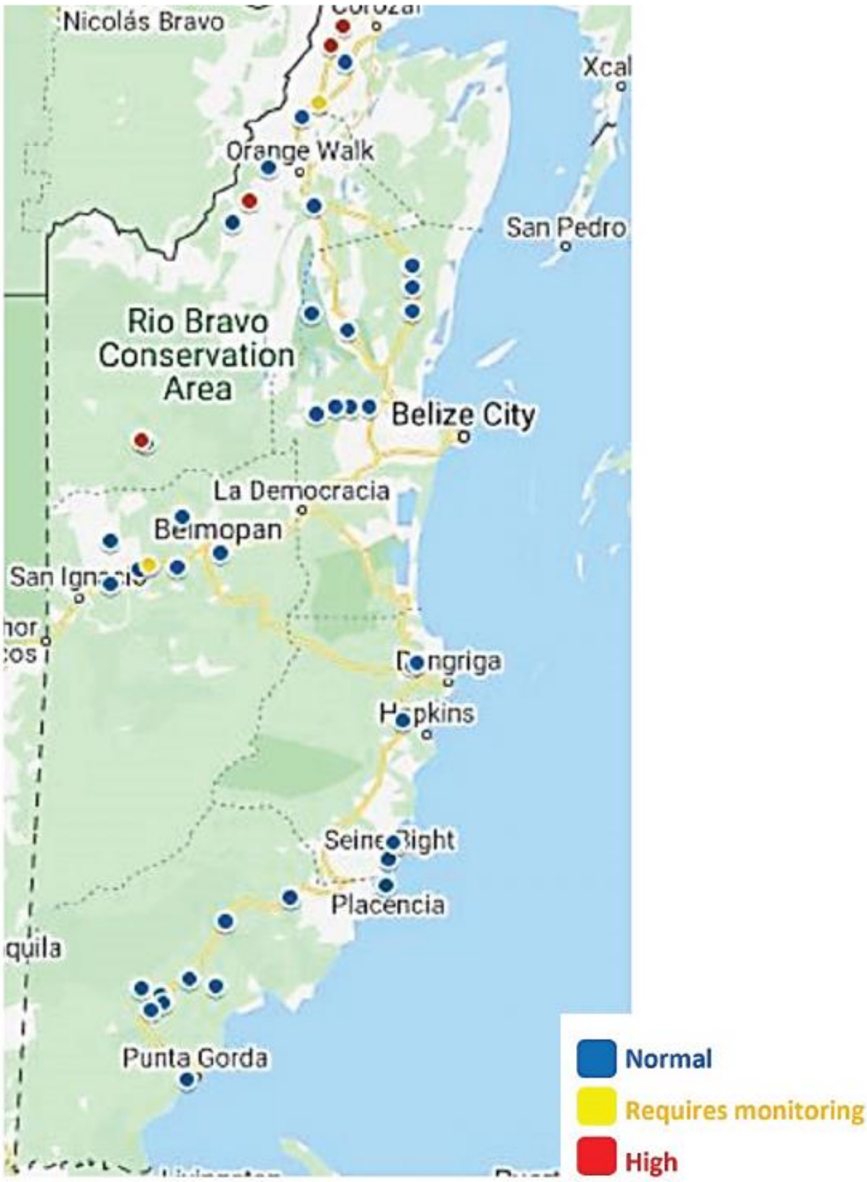

Figure 4.1: Summary of nitrate levels in rural water supply systems in Belize (Husaini, 2020)

Another assessment conducted in 2022 on the groundwater well sources for Copper Bank village revealed test results that were unsuitable for human consumption.[14] Figure below shows the tests results of water taken from source well.

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[14] Conducted by a local firm: TNCE, 2022

Table 4.4: Test results of water taken from the Copper Bank RWS

Sample location parameters	CM4	CM5
Hardness, total	302	322
Sulphate	68	57
Nitrates	58.23	60.75
Reactive Phosphorous, Orthophoshate	0.16	0.22
Total Suspended Solids	0.8	0.4
pH	7.41	7.23
Conductivity	1298	1135
Total Dissolved Solids	844	725
Salinity	0.653	0.562
Total Coliforms	TNTC	TNTC
E-coli	310	170
Fecal coliforms	TNTC	TNTC

Note the high concentration of bacteria, conductivity, nitrates, and sulphates. This is a sample of the type of water being distributed to residents of the village. Note that a reverse osmosis plant was installed to treat this water before distribution, however the plant has not been operational in over a decade.

Summary

Limited data on groundwater quality exists for Belize, and systematic monitoring of environmental groundwater quality is not currently carried out. However, the Ministry of Health does undertake periodic drinking water quality testing of rural water supply systems on a periodic basis for the purposes of public health.

Based on stakeholder consultations undertaken for this project the main groundwater quality issues in the New River area include:

- Increasing nitrate concentration, and contamination of water supplies with excessive nitrates in some water supply systems, potentially due to the proximity of wells to septic systems and soakaways, as well as increasing rates of fertilizer application in agricultural areas. For example, BWS has had to stop using two of its wells in the vicinity of Orange Walk due to high nitrate levels. A study by Husaini (2020) also revealed locations where nitrates were higher than drinking water standards (see Figure 4.1). Recent occurrences of eutrophication in the New River are also potentially due to high levels of nutrients during dry season conditions, and may be linked to increasing nutrients in groundwater, although this has yet to be proved.
- Loss of wells to high salinity in coastal areas. There are high concentrations of chloride (Cl) along the coast and rivers that are influenced by the tide. There is also evidence of Cl in inland wells in Northern regions possibly due to salts dissolving in calcareous sediments (UN, 2022). Some increased hardness and sulphates have been found in some areas, especially in the Corozal District (UN, 2022). However, mapping of areas at risk from saline intrusion is not available and further data collection on this aspect would provide more quantitative information on where this is occurring.
- The contamination of aquifers with agrochemicals and pharmaceuticals. Very limited testing of these persistent organic pollutants has been undertaken, and mainly in surface water rather than groundwater, and further data collection is needed to understand this risk.

The karst system provides very little filtration in most areas, so there is likely to be water quality issues and sources are susceptible to development, pollution, agricultural impacts, and overpopulation (Polk et al., 2013).

4.4 Groundwater vulnerability

4.4.1 Types and sources of groundwater pollutants

Groundwater can be contaminated by both natural and human-induced sources. Natural sources of groundwater contamination include minerals, salts, and bacteria that are present in the earth's crust. Human-induced sources of groundwater contamination include industrial and agricultural chemicals, sewage, and waste disposal. The most common human-induced contaminants are pesticides, fertilizers, gasoline, oil, and heavy metals. In addition, landfills, waste lagoons, and underground storage tanks can also be sources of groundwater contamination.

Point source pollution refers to a specific, identifiable source of pollution, such as a pipe or ditch, that discharges pollutants into a body of water. In the case of groundwater, point source pollution can occur when contaminants are discharged directly into the groundwater, either through a well or a crack in the earth's surface. Examples of point source pollution on groundwater include industrial discharge of chemicals, septic tank leaks, and leaking underground storage tanks.

Non-point source pollution is typically caused by runoff, precipitation, atmospheric deposition, drainage, seepage. Unlike pollution from industrial and sewage treatment plants, NPS pollution comes from many dispersed sources. The pollution occurs when runoff from rainfall flows over and through the ground, picking up and transporting both natural and human-made pollutants, and ultimately depositing them into bodies of water such as lakes, rivers, wetlands, coastal waters, and groundwater.[15]

Groundwater in Belize is vulnerable to contamination from a variety of sources, including septic systems, agricultural runoff, and industrial activities. Effective management of water quality is essential to protect the groundwater resource, and sustainable practices such as proper wastewater treatment, groundwater monitoring, and education and outreach programs can help to minimize the impacts of contamination. Factors that affect groundwater vulnerability include:

- **Aquifer type:** The type of aquifer (e.g., sandstone, limestone, etc.) and its physical characteristics, such as permeability and porosity, can influence groundwater contamination vulnerability. *See section 2.2 of this report that shows the predominant limestone formations in the project area.*
- **Soil type and thickness:** The type of soil overlying the aquifer, as well as its thickness, can influence water flow and the rate at which contaminants can penetrate the soil and reach groundwater.
- **Groundwater recharge rate:** The rate at which groundwater is replenished can influence its contaminant vulnerability. Aquifers with low recharge rates are more vulnerable because pollutants accumulate over time.
- **Land use:** By releasing chemicals and pollutants into the soil and groundwater, human activities such as agriculture, industry, and urbanization can increase the risk of groundwater contamination.
- **Geology and topography:** Groundwater vulnerability can be influenced by an area's underlying geology and topography, which control the movement of water and contaminants.
- **Pumping groundwater** for human consumption can disrupt the flow of water and make the aquifer more vulnerable to contamination.
- **Climate and weather conditions**, such as drought or heavy rainfall, can affect the recharge rate and flow of groundwater, thereby increasing its vulnerability.

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[15] EPA: epa.gov

The water quality data provided gives some insight as to the health of the shallow aquifers in the New River area. Data provided by the Ministry of Health and Wellness as well as BWSL shows that in general, the groundwater abstracted from wells in the project area has high values for hardness, nitrate levels and total dissolved solids.

Domestic/municipal pressures on groundwater

Domestic and municipal usage can affect the vulnerability of groundwater in several ways. One major way is through the release of pollutants and waste products into the groundwater. For example, septic systems and sewage treatment plants can release untreated or partially treated waste, which can contain pathogens, chemicals, and other pollutants. The water production from both BWS and RWS systems totals 2.5 million m^3 annually for the Corozal and Orange Walk districts. If we consider a distribution loss of 25%,[16] it is reasonable to assume that approximately 1.9 million m^3 of wastewater is being discharged into soakaways and septic tanks within the watershed.

Other potential sources of groundwater pollution originate from the numerous and unregulated open dump sites scattered throughout the project area, including the dumping of garbage in unused wells and the use of dry wells as septic systems. Open dumpsites can have a significant impact on the quality of groundwater. When waste is dumped in open dumpsites, it decomposes and produces a variety of chemicals and substances, including organic matter, heavy metals, and pathogens – these are known as leachates.

Leachates forms when water (rainfall) encounters waste material and carries dissolved or suspended pollutants with it as it percolates through the soil. Groundwater contamination from open dumpsites can have serious health consequences for those who rely on the water supply. In addition to contaminating groundwater, open dumpsites can also contribute to surface water pollution, air pollution, and soil degradation.

Agricultural pressures on groundwater quality

The use of pesticides, fertilizers, and other chemicals in agriculture can lead to contamination of groundwater. These pollutants can seep into aquifers and contaminate the water, making it unsafe for human consumption and damaging ecosystems. Agricultural chemicals and fertilizers are essential tools for modern agriculture, but they can also have a significant impact on the vulnerability of groundwater. These chemicals and fertilizers can contain a wide range of pollutants, including heavy metals, pesticides, and nutrients, which can seep into the ground and contaminate aquifers.

One of the main ways in which agricultural chemicals and fertilizers can affect groundwater is through leaching. These chemicals and fertilizers can leach into the soil and travel deep underground, where they can contaminate aquifers and affect the quality of the water. Leaching can also occur when heavy rainfalls occur, and the chemicals and fertilizers are not properly managed and stored.

Another way that agricultural chemicals and fertilizers can affect groundwater is through runoff. Runoff can occur when rain or irrigation water carries these chemicals and fertilizers over the surface of the land, where they can then enter surface water bodies, and ultimately reach the groundwater. The use of agricultural chemicals and fertilizers can also lead to eutrophication, which is the excessive growth of plants and algae due to an oversupply of nutrients. Furthermore, this can lead to oxygen depletion and can also affect the quality of the water as is evidenced by the annual eutrophication events being experienced in the New River.[17]

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[16] Current average Non-revenue water statistic for BWS

[17] Drexler, K, Socio-Ecological System Impacts of Anthropogenic Pollution on New River Communities in Belize, 2019, Global Security and Intelligence Studies

According to the most recent figures, Belize ranks 11th in the world (out of 161 countries) in fertilizer use per hectare of arable land.[18] Belize imported a total of 40,000 tonnes of fertilizer in 2019 – 16,500 tonnes of nitrogen, 14,500 tonnes of Phosphate and 10.0 tonnes of Potash.[19] The graph below shows the increase in fertilizer import and usage by the country. There has been a dramatic increase in fertilizer use in recent years. Between 2012 and 2020, the average annual amount of fertilizer imported was 10,000 tonnes, which is nearly triple the average annual import of 3,500 tonnes between 2002 and 2011.

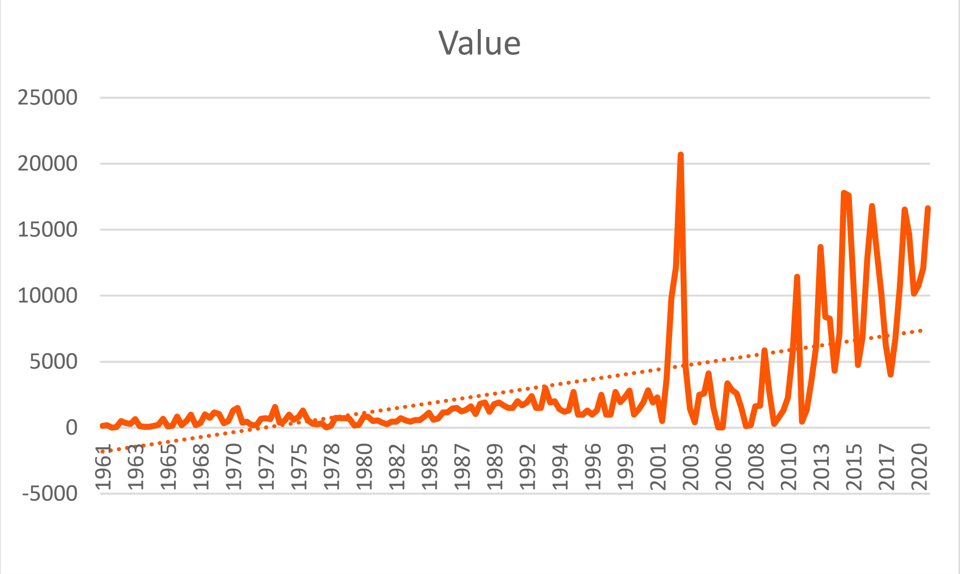

Figure 4.2: Tonnes of fertilizer imported by Belize.

Industrial pressures on groundwater

The current industrial players within the project zone utilizes approximately 1% by volume of the known total groundwater abstraction for the area. Though this is a small amount, the issue here is not quantity of groundwater abstracted, but more on the quantity and quality of the effluent that is being released into the environment by these industries. The two main industrial users are the BSI/ASR and Caribbean Chicken. These two industries abstract water mainly for processing purposes. For the sugarcane factory, water is mainly used in the processes such as washing and cleaning the sugarcane before crushing as well cooling for the various boilers. In a chicken processing plant, water is used for cleaning and washing chicken carcasses, scalding and defeathering, chilling and sanitation. The resultant wastewater from the above-mentioned processes will exhibit one or more of the following characteristics: a high nutrient load; high temperature, or high toxicity from cleaning chemicals.

How these industrial wastewater effluent streams are treated is of utmost impermanence to the health of the surround waterbodies – both surface water and groundwater.

4.5 Gender and groundwater in Belize

There has been limited integration of planning and institutional processes that mainstream gender within the water sector in Belize. Traditionally, these sectors were viewed as distinct with limited documented work demonstrating the water and gender nexus. Water supply policies do

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[18] https://www.theglobaleconomy.com/rankings/fertilizer_use/

[19] https://www.fao.org/faostat/en/#data/RFN

not encapsulate linkages between gender and water. The National Integrated Water Resources Management Policy for Belize 2008 does not include an integrated gender policy position. The Policy however identifies the need to have inter alia, social assessments to inform water resource planning (BEST, 2008). Likewise, the National Gender Policy (2013) calls for implementation of strategies aimed at increasing household and water safety for children of all ages. The Policy, however, does not go further in advocating for intersectoral connections and planning that will ensure that gender considerations are mainstreamed into national or sectoral water plans; and further in their monitoring or implementation.

Table 4.5: Summary of Policy Analysis

Policy	Gender Considerations	Clearly stated mandate for inclusion of various genders (and other vulnerable groups) in policy	Specific provisions to ensure consideration of gender equity and gender analysis as part of policy implementation
National Climate Change Policy Strategy and Action Plan to Address Climate Change in Belize	Limited Presence	The policy lists gender equity and non-discrimination in access to opportunities as one of its guiding principles	No
The Revised National Gender Policy	Presence	Mandate	The policy lists the mainstreaming gender into disaster management programmes as one of its priorities
NAP for the Agriculture Sector, and Water as it relates to Agriculture	Presence	The NAP states that the process must follow a country-driven, gender-sensitive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems.	Ensure all policies integrate gender and climate change perspective and consider literacy levels
National Integrated Water Resource Management Policy (including Climate Change) for Belize	Absence	The policy does not mention gender	No

Adapted from: Caribbean Natural Resources Institute. 2021. Report of the Gender-based Climate Resilience Analysis for Belize.

Men often dominate water management roles and technical roles within the sector. The water sector, like in many Sciences, Technology, Engineering and Math (STEM) disciplines in Belize, is traditionally male dominated. Often decisions related to the sector and hazard proofing water resources are made without women's participation (CANARI, 2021). Moreover, even when women hold technical leadership positions, they are constrained by patriarchal challenges to their decision-making styles. The Caribbean Development Bank (CDB) Country Gender Assessment for Belize (2016) identified that in electricity and water supply economic activity area, female employment was 0.172 per 1000 population and that male employment was 0.870 per 1000 population.

The National Hydrological Service is composed of a technical team of four where of the four, there are three Hydrological Technicians who are all men and the Principal Hydrologist is a woman. While the non-technical roles within the NHS are filled by women and the Officer-in-charge of the NHS is a woman, technical expertise remains uneven and therefore there is a gender gap.

The NHS is complemented by twenty-four (24) Hydrological Observers across Belize. These observers are community residents who monitor hydrological stations and report gauge water level readings to NHS twice daily. These Observers are integral to the NHS Early Warning System. Of the 24 Hydrological Observers, ten (10) are women. In Northern Belize, only two (2) are women.

The NHS programming is gender neutral when addressing sectoral and community needs. This is in line with the current IRWM policy.

The BWSL has a board composition of 1 woman (9%) and 10 men (91%) Board members. The Management Team is comprised of 41% women and 59% men. The female managers hold both traditional and non-traditional jobs within the company. Within the Technical Services Department there is a ratio of 1:4 women to men. This Department is however, headed by a woman. While the Technical Services Department is male dominated, BWSL has seen increased numbers of women working in STEM related fields such as in their Water Treatment Labs performing water quality testing. Similarly, three Water Treatment Plant Operators are women. The Company provides opportunities for cross training and encourage non-discrimination in training opportunities; however, often applicants select training in traditional gender areas.

The BWSL has developed a Gender Policy which will be rolled out in 2023 with the appointment of Gender Champions across the Company, and the recruitment of a Gender Specialist. The Policy approach is based on equity and diversity and the principle of ‘Leave no one behind’. While most of the policy actions focus on the administration of the BWSL, the operational considerations for the Water Sector are expected to dovetail from administrative gains.

BWSL has in the past proposed a tariff structure that would allow for varied water rates based on socio-economic status, ultimately decisions that would allow for gender and social inclusion in costing the water resource is made by the Public Utilities Commission. Therefore, decisions that may allow for improved integrated management of the water resource from a socio-economic and gender perspective are not within the sphere of control of BWSL.

At the Ministry of Rural Transformation, Community Development, Labour and Local Government, there are no women within the Rural Water Supply and Sanitation Unit. Of the twenty-three Department of Rural Development staff, two women hold technical positions. Of note is that the Coordinator of Rural Development is female.

Of the 18 water boards in the Orange Walk District, 3 (16%) are chaired by women. In the Orange Walk District, 33% of water board representatives are women, while 67% are men. Of the 10 water boards in the Corozal District, 4 (40%) are chaired by women, and 6 (60%) by men. In the Corozal District, 35% of appointed water board representatives are women and 65% are men.

Water demand and consumption data is not disaggregated by sex or by sex of head of household.

Population data is presented and therefore full assessment on the risks of water supply issues on men and women is not possible. Instead, based on post censal estimates and population data, assumptions can be made on how different groups of the population within administrative districts may be impacted by water related risks.

Gender considerations in groundwater demand and exposure to groundwater risks.

In Northern Belize, particularly in rural communities, traditional gender roles prevail with women taking up the lion’s share of responsibility in the Domestic Sphere. This position is validated by Labour Force participation rates which shows that unlike central Belize, there is a significant gap between labour force participation of women and men in northern Belize. In Corozal, female participation in the labour force is 40.9% as compared to 83.5% for males (Rawwinda Baksh and Associates, 2016). In 2021, the Enabling Gender-Responsive Disaster Recovery, Climate and Environmental Resilience in the Caribbean (EnGenDER) study- Gender Inequality and Differential Impact of Climate Change and Disaster Risk and Cost of Inaction for Belize revealed that the main users, and conservers of water for the household are women (Caribbean Natural Resources Institute, 2021). As primary carers for dependents, water availability is critical for women in ensuring efficiency in exercise of care roles. This is so because children, particularly those under five, are at risk of waterborne parasites and child mortality (ibid). Elderly persons are also at risk from the exacerbation of these conditions. Women have key responsibilities concerning the supply of water, both for household use and family farming.

In Belize, 56% of the population lives in rural areas where groundwater is a vital source for fresh water and represents almost 95 per cent of the fresh water supply (HR Wallingford, 2022). There is near parity in percentage of men (50.6 and 49.4) and women (50.5 and 49.5) living in rural Orange Walk and Corozal respectively. Water scarcity is expected to impact more males than females in terms of sheer numbers. However, the reality of water use within the norms of rural Belizean households may mean that women and dependent groups are disproportionately affected. Water scarcity increases the time and energy expended on domestic duties and reduces potential time available for undertaking paid work (HR Wallingford, 2018). Moreover, socio-economic vulnerability is exacerbated in Caribbean countries like Belize where over 40% of the households are singly headed by females who hold care and productive roles (Rawwinda Baksh and Associates, 2016; Caribbean Natural Resource Institute, 2021).

A UNICEF Menstrual health Management study (2018) showed that there is currently a gap in provision of adequate water supply and hygiene facilities for girls in rural schools. Inadequate water, sanitation and hygiene (WASH) resources present significant challenges for women and girls, particularly during their menstrual cycle, which increases their exposure to health crises (UNWOMEN 2021). The study validated that where water is in short supply, girls' education and health are impacted. Girls may face increased absenteeism, and distraction at schools, therefore impacting their life outcomes (UNICEF,2018).

In addition to household use, women in Belize are dependent on water resources for their livelihoods. Water insecurity can have implications for livelihoods in the tourism and agriculture sectors as well as human health and sanitation, especially in the event of a natural disaster (CANARI, 2021). Women and other vulnerable groups, including remote rural and indigenous populations and youth, will be significantly affected by these impacts and other shocks on the priority sectors. This is due to the type of roles and work they undertake in these sectors, and their limited access to resources and services due to issues of informality, lack of tenure/ownership and cultural and traditional values (ibid).

Agricultural livelihoods and food security are impacted by water shortages. Limited access to resources and public services, including piped water, makes women and their dependents more vulnerable due to limited access to and the quality of groundwater (UNWOMEN, 2021). The 2011 Agricultural Census revealed that 30% of farmers are females who are in charge of taking decisions in all activities in their farms and more than 25% of women work in irrigation and water management (IFAD, 2019). In 2021 there were approximately 2,991 female farmers (21.9%), 10,560 male farmers (77.4%) and 87 companies/schools (0.64%) on registered on the Ministry of Agriculture, Food Security and Enterprise's information system, BAIMS (Ministry of Agriculture, Food Security and Enterprise, 2021).

Stakeholder interviews

Mrs. Tennielle Hendy - Principal Hydrologist- National Hydrological Service

Mr. Ismer Ortega - Northern Regional Coordinator- Department of Rural Development

Mr. Haydon Brown - Human Resource Manager- Belize Water Services Limited

Ms. Sheryl Terry - Assistant Human Resource Manager- Belize Water Services Limited

5 Summary of findings and recommendations

Groundwater is widely exploited in Belize for domestic, industrial, and agricultural consumption. Fifty seven percent (57%) of municipal and domestic water demand is met from groundwater sources at the national level, and in rural communities served by rudimentary water systems or private supplies this figure is much higher. Population growth is likely to increase domestic and municipal demand by around 36% by 2060, if per capita consumption increases this may be an underestimate. Data on industrial and agricultural groundwater use are either dated or incomplete and require urgent updating.

Although the general extent of groundwater bearing formations are known, limited information exists on the hydrogeological characteristics of aquifer systems in Belize, for example in northern districts groundwater is extracted from shallow and heterogenous aquifer systems with variable yields and water quality. The quality and potential yield of deeper aquifers remains largely unexplored.

Climate change is projected to increase temperatures in Belize, while rainfall is projected to decrease. This will result in lower groundwater recharge, declining river flows and increasing crop water demands and incidents of drought. The most severe impacts are likely to be felt across the drier northern groundwater provinces and may require the increasing exploitation of deep groundwater resources in the Campur limestone formations which are believed to exist beneath the shallow aquifer systems and have been little exploited or explored to date. It is vital that exploitation of these deeper aquifers is carried out in a sustainable manner as climate change progresses.

Climate change in combination with increasing agricultural development and application of fertilizers, especially in northern Belize, poses a risk to groundwater resources both in terms of reduced groundwater recharge and reduced river flows, especially in the dry season, coupled with increasing contamination (and reduced dilution) of groundwater with fertilizers and pesticides. Recent eutrophication events in the New River risk becoming commonplace unless action is taken to determine the specific causes of contamination and develop mitigation measures.

Key recommendations:

1. Mandatory water abstraction licencing and submission of actual abstraction volumes is recommended to increase confidence in the data, for both consumptive and non-consumptive uses.
2. An updated estimate of agricultural water demand is urgently required to better understand its impacts on water resources.
3. Systematic efforts are required by the NHS to collate, store, and interpret well logs and pumping test results for newly drilled wells across the country. This would offer an opportunity to improve the understanding of hydrogeological characteristics.
4. Strengthening the regulatory arrangements for licensing of groundwater abstraction, coupled with improved data collection on groundwater abstraction is required in order to allow the NHS to more effectively manage groundwater resources for their long term sustainable development.
5. Further, given the increasing threats to groundwater and surface water quality, especially in northern Belize, improved data collection and sharing on diffuse and point source pollution, coupled with actions to manage and reduce pollution are needed to limit the risks of a long-term deterioration in groundwater and surface water quality.
6. Systematic and long-term monitoring of groundwater level and quality, and surface water quality, volumes, groundwater abstraction rates is required to track long term trends and plan mitigation measures.
7. Improved data collection on diffuse and point source pollution sources is critical to inform management actions and better qualify the loadings of contaminants into aquifers and river systems.

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