Assessment of Groundwater Resources in the Southern Coastal Water Province of Belize Referred to as Savannah Groundwater Province

Inception Report

December 2013

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1. Introduction

This Inception Report is presented in accordance with the Contract No. GCCA/PS/2013/04 between UNDP and GEOMEDIA Ltd. signed on 4th November 2013 concerning the Project **Assessment of Belize's groundwater resources in the southern coastal water province referred to as the Savannah Groundwater Province**.

This first Inception Report is a product of an initial action of the Project providing detailed elaborated time plan of the entire Project as well as methodology determining the exact focus and scope of the exercise. Presented Inception Report is based on review of data and information available from open sources.

2. Project background

2.1. Climate change and groundwater

According to the World Meteorological Organization, Belize is the country with maximal average value of water availability per capita of about 58,500 m^3/year (CEPAL, 2003). However, three main factors cause problems in meeting demands for various water uses: seasonality in supplies, quality and population distribution.

Like many other low-lying coastal nations, Belize is vulnerable to the effects of climate change. Its geographical location leaves the country exposed to the risk of rising sea levels and increasing frequency and intensity of tropical storms. Its economic dependence on natural resources heightens its vulnerability to rising temperatures and the resulting impacts on agricultural productivity, fisheries ecosystems, and other economic sectors. Rising sea levels will likely lead to the inundation of coastal agricultural land and the salinization of groundwater. The anticipated effects of sea-level rise, flooding, stronger storms and hurricanes as well as the salinization of groundwater supplies threaten the coastal communities of Belize. It is obvious that water supply management shall be evaluated for normal as well as for emergency conditions as mentioned here above. National Emergency Management Organization developed National Plan-Relief and Supplies Management outlining necessary measures to be taken for acquiring and distributing relief supplies before and after an extreme event.

With a meter rise in sea level, none of the remnant cayes in Belize will have a source of potable ground water. Some of the coastal plains will experience high levels of seawater intrusion and rising water tables. This will lead to a drastic decrease in the volume of the fresh water lens and intensify the potential for contamination of the lens from domestic and industrial waste. Surface water sources could be enhanced only if the climatic variation favors an increase in rainfall in the country (UNFCCC, 2002).

Yet another impact of climate change on the water sector is increased frequency of salt water intrusion. This will increase as sea levels rise. Salt water intrusion is regarded as the displacement of fresh surface water or groundwater by the advance of saltwater due to its greater density. It usually occurs in coastal or estuarine areas (e.g. either from reduced runoff and associated groundwater recharge or from excessive water withdrawals from aquifers) or increasing marine influence (Bates et al 2008; UNFCCC, 2009).

2.2. Groundwater assessment in Savannah Province

Climate change discussions in recent years have emphasized the need to effectively manage and protect groundwater resources which are necessary to sustain economic growth and guarantee quality of life also with respect to frequent emergency situations occurring in Belize (NEMO, 2004).

Groundwater is particularly important for domestic supply accounting for 95% use (Ballestero et al., 2007). However the lack of information regarding groundwater leads to a difficulty in the management of future water resources under climate change and increases the vulnerability of communities.

The focussed groundwater and surface-water systems are hydrologically interconnected and function together to provide water for public, industrial, agricultural, and recreational use. Knowledge of these complex systems gained through scientific research is paramount to the protection and sustainability of this irreplaceable resource.

Therefore, this groundwater assessment Project was put in place, focusing on Groundwater Savannah Province, situated in south-eastern Belize (Fig. 1), with considerable demand for water supplies for the villages, tourism, agriculture and aquaculture developments.

The Savannah Groundwater Province extends along coastal Belize from the extreme south-eastern Belize district to extreme north-eastern Toledo District in the length of about 80 km. Its eastern boundary is formed by the coastline. The investigated area of Groundwater Savannah Province represents a regional hydrogeological structure including recharge area along the eastern slopes of the Maya mountains (e.g.

Annex 1). This province extends along the eastern slopes of the Maya mountains to the coast. Its width ranges from 10-15 km in the north up to 25 km in the south.

The total area of Savannah groundwater province is 1,500 km^2 (Williams, 2011). In 2010 Savannah´s population was estimated at 21,941 inhabitants. In total 25 Rudimentary Water Systems are situated in this groundwater province. According Williams (2011), Savannah Groundwater Province covers 21 operating tourists facilities, 9 tourist facilities under construction, 4 approved tourist facilities awaiting funding, 1 international airport under construction, 12 aquaculture farms & processing facilities, approx. 100 km^2 of citrus farms, approx. 90km^2 of banana farms, 33 production wells and 9 abandoned wells.

Fig. 1 District map of Belize with delineated Savannah Groundwater Province.

3. Project scope

This Project was implemented in the frame of the project of the Government of Belize entitled *Enhancing Belize's Resilience to adapt to the Effects of Climate Change – 00083646.*

The objective of the consultancy is to support the Government of Belize, Ministry of Natural Resources and Agriculture in completing an assessment of Belize's groundwater resources in the Savannah Groundwater Province.

Specific objectives of this assessment include the following:

- Overall snapshot of groundwater conditions as they were known before this Project

- Provision of an aggregated overview of the current groundwater potential, estimates of the ground water potential in the delineated region
- Proposal of location of new wells to be drilled and drilling, supervision
- Extension of set of existing hydrological, hydrogeological and geological data by measurements of newly drilled wells
- Groundwater and surface water sampling
- To the extent possible, determine the extent of ground water resources degradation based on past and current land use practices
- Provision of Classification of the hydrogeological characteristics of the province, a definition of its boundaries
- Integrated groundwater assessment study which is to serve as the basis for regional groundwater development master plan
- To the extent possible, identification complex relationships and interactions of various components of geo-hydrological environment by means of GIS database
- Investigation of processes of sea water intrusion
- Develop a conceptual site model of hydrogeological conditions
- Construct a groundwater flow model to show current characteristics of groundwater flow
- Model simulation of proposed scenarios of development in groundwater management reflecting growing population centers and large expansion in tourism, aquaculture and agriculture

This assessment study shall focus on those areas which support growing population centers as well as those areas which are expected to support large expansions in the various developmental sectors including tourism, agriculture and aquaculture.

For those areas supporting population centers a more detailed assessment of the spatial and vertical extent of the groundwater quality and quantity is required as a means of determining the feasibility of utilizing groundwater resource as an alternative for water supply options in the light of climate change.

The project will deal with quantitative assessment of groundwater resources, delineation of regional and local structure features and dynamics of groundwater. The current interpretation of Savannah Groundwater Province in terms of structure and boundary conditions shall be validated. The methods of systematic analysis of groundwater structure shall be described and discussed. The issue of sea level rise and impact of various scenarios on groundwater shall be evaluated.
The current and future proposed groundwater extraction from the studied structure shall be investigated.

Further part of investigation shall involve potential (and existent) groundwater pollution by anthropogenic sources – aerial pollution by agriculture, point sources such as businesses, tourism, residential.

Special topic of investigation shall be the processes of sea water intrusion, negatively influencing groundwater quality. This process may be principally caused by global climate change and resulting rise of sea level as well as locally by aquifer overexploitation.

4. Implementation plan

4.1. Concept of activities

The Project activities are split into 3 principle work packages (WP) which are further divided into subtasks according to the following structure:

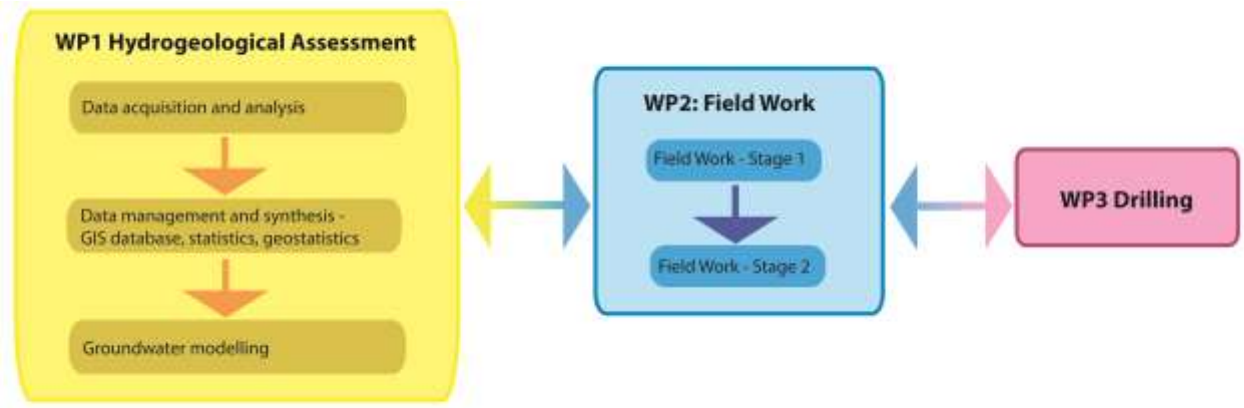

Fig. 2 General concept of Groundwater Assessment of the Savannah Province.

WP1: Hydrogeological assessment
Project activities encompassing WP1 shall take place in the main office of GEOMEDIA in Prague.

WP2: Field work
Project activities encompassing WP2 shall take place in dedicated field as well as the project office / contact point which shall be established for the Project duration in Belize.

WP3: Drilling
Project activities encompassing WP3 shall take place exclusively in dedicated field according to previous well siting

4.2. Assessment methodology

This Groundwater Assessment shall be completed to be consistent with the requirements outlined in the Request for Proposal.

WP1: Hydrogeological assessment

WP1 is subdivided into following subtasks:

- WP1a: Data acquisition and analysis
- WP1b: Data management and synthesis - GIS database, statistics, geostatistics
- WP1c: Groundwater modelling

<u>WP1a: Data acquisition and analysis</u>
The success of any groundwater assessment study, to a large measure depends upon the availability and accuracy of collected/measured/recorded data required for that study. Therefore, identifying the data needs of a particular study and collection/monitoring of required data form an integral part of any groundwater assessment&modelling exercise.

The first phase of a groundwater assessment consists of collecting relevant existing geological and hydrological data on the Savannah Groundwater Province. This should include information on surface and subsurface geology, water tables, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics and boundaries, and groundwater quality. If such data do not exist or are very limited, efforts will be carried out to gather them during field works in WP2.

Data are generally collected from existing reports of different agencies and departments in Belize as well as from international sources. The collected data relevant for comprehensive assessment of the groundwater potential are covering the areas of topography, land use, meteorology, hydrology, geology and hydrogeology.

Particular focus has been also given to review the existing water facilities (wells) and potential sources of groundwater contamination.

This stage is also subject of detailed time planning considering succession of Project activities.

WP1b: Data management and synthesis - GIS database, statistics, geostatistics

This stage is focusing on implementation of available data acquired within previous task into GIS database. For handling groundwater data, the GIS-technology is well suited as it enables concurrent handling of locational and attribute data. GIS also offers technological avenues for integrating the variety of data sets in both qualitative and quantitative terms. The data analyses by means of the geographical information system shall enable to identify complex relationships and interactions of various environmental components in terms of hydrogeology, geology, contamination, etc.

If applicable, available data on hydrogeological parameters and water facilities in the delineated area shall be characterised and analysed by means of statistical and geostatistical methods.

After gathering available existing data relevant for the Project, it will be possible to identify lacks and deficiencies in data set primarily concerning hydrogeological parameters. In order to achieve reliable Groundwater Assessment, it is necessary to complete the data set with new hydrogeological and geological data within the delineated area. Therefore, it will be proposed in this stage a well test program describing type and duration of well testing and specifying hydrogeological characteristics to be determined. The well testing will be performed on newly drilled wells sited and designed within WP2 and drilled within WP3.

WP1c: Groundwater modelling

Conceptual models are a first step in defining the list of data needed to evaluate a given water resource issue in a given setting. A conceptual model is based on a number of assumptions that must be furthermore verified in. It represents a complex natural aquifer system and it develops an understanding of groundwater flow directions, sources, and discharge areas. Once the important relationships and the available data are known, data gaps can be filled and the conceptual model is used to guide efforts to create an analytical or numerical model.

Numerical groundwater modelling shall be applied to enable proper assessment of natural hydrogeological conditions and to provide a rough estimate of the status of the groundwater resource and what volume might be abstracted without damaging local surface aquatic ecosystems over the long-term.

Groundwater modelling shall also include simulation of proposed scenarios of growing population centers and large expansion in tourism, aquaculture and agriculture in order to properly asses the availability and sustainability of encountered groundwater resources for public demands.

Model calculation is going to be performed by means of MODFLOW simulation package.

WP2: Field work

Conducting a site visit at the beginning of Field work shall verify and supplement the information collected from the records review. In particular, the site visit is used to confirm locations of wells, local land use, surface water body features and obvious sources of potential groundwater contamination (industrial land use, landfills, etc.).

WP2 is subdivided into following subtasks:

- WP2a: Field work - stage 1
- WP2b: Field work - stage 2

WP2a: Field work - stage 1
The stage WP2a shall focus on:
- mapping, verification of the geological and hydrological data;
- measurement of existing wells;
- groundwater and surface water sampling;
- proposal of location and design of the wells to be drilled within the project;
- supervision of initial drilling.

Mapping provides the data and information needed to develop an accurate inventory of groundwater resources, including the classification of aquifers, springs and other water resources; mapping also provides assessments of resource vulnerability.

Mapping activities shall also include verification and documentation of existing wells covering groundwater level measurements. Existing wells (Annex 1) will be verified for potential use as test wells.

Existing wells may be used as test wells if the well owner agrees to participate in the testing program; the well construction characteristics are known (e.g. well depth, casing length, geologic formations intercepted); and the well is in good condition (i.e., meets well construction regulation requirements and has been properly maintained).

Water samples should be collected from selected test wells. Samples should be collected at the end of the step drawdown or constant rate pumping test (last hour of pumping test).

It is expected to collect approximately 100 water samples including both surface and groundwater. Most of them will be subject of field determination only to obtain preliminary and orientation results and rest of samples will be delivered to local laboratory for detailed chemical analysis.

Laboratory determination of water samples shall include the following:

- *Physical parameters* – pH, conductivity
- *Summary parameters* – sum of anions, sum of cations, total hardness, calcium hardness, magnesium hardness, the content of dissolved solids,
- *Inorganic parameters* – NH_4, Cl, NO_3, NO_2, F, PO_4, SO_4, CO_3, HCO_3, CO_2,
- *Cations and metals* – Ca, Mg, Na, K, Mn, Fe, Cd, Cr, Cu, Ni, Pb, Zn
- Optionally – *petroleum substances, chlorinated hydrocarbons, phenols, pesticides*, etc.

Additional parameters may be required depending on local geology, adjacent land uses and the potential for contaminant impacts.

Following characteristics of water samples shall be determined in field:

Using field devices:
- *Temperature*
- *Dissolved oxygen*
- *Conductivity*
- *pH*
- *Redox*
- *Salinity*

Subjectively:
- *Color*

- *Transparency*
- *Odor*

Well siting is subject of this Project stage as well as specification of well design, number and depths of newly drilled wells. The test wells should be located such that the hydrogeological conditions across the site are adequately represented.

During this stage of Field work, the project team will ensure the supervision of well drilling and installation works, development, pump testing as well as professional assistance and consultancy to the subcontracted drilling company.

<u>WP2b: Field work - stage 2</u>
The stage WP2b shall focus on:

- supervision of drilling activities;
- management, supervision and interpretation of pump tests;
- additional water sampling.

This stage of Field work shall take up the supervision of drilling activities. This field program shall include the final installation of test wells from newly drilled wells that will be used for pumping tests and also for additional water quality sampling. The test wells must be fully developed prior to performing the pumping tests. A test well may be considered fully developed when a minimum of suspended solids is observed in the groundwater, and field parameters such as temperature, specific conductance, and pH have stabilized.

WP3: Drilling

It is expected that based on the intermediate results of WP 1 and 2 up to 5 groundwater exploration wells will be drilled with the purpose to verify and significantly improve the recent knowledge of groundwater structures as well as enable further monitoring to better manage the available groundwater resources.

The well design will be formulated and location will be selected so that the new wells can be also used in controlled regime to improve local water supply.

Well testing to determine hydraulic parameters of the aquifers as well as the effective yield shall be performed on all newly drilled wells. The well test program will be defined within the WP 1.

Drilling will be carried out by local subcontractor. GEOMEDIA Ltd. is in negotiation with local drilling companies to carry out drilling and related activities.

4.3. Timeline

The Project shall be carried out between 4th November 2013 and 18th August 2014, as agreed by the Contract No. GCCA/PS/2013/04.

Reporting

The Project work is divided into three reporting periods. Anticipated milestones are as following:

Output	*Completed by:*
Inception Report	6th December 2013
First Technical Progress Report	30th April 2014
Final Technical Report	18th August 2014

Inception Report:
Inception Report provides with detailed elaborated time plan of the entire Project as well as methodology determining the exact focus and scope of the exercise. The Inception plan also summarizes review of documentation available from open sources.

First Technical Progress Report:
First Technical Report shall cover exhaustive description and preliminary findings of field works including mapping, sampling, measuring, well testing as well as drilling activities accompanied by photo documentation. This will introduce all available data being acquired since the beginning of the project including both office and field activities.

Final Technical Report:
Final Technical Report and its annexes shall include all findings and data resulting from WP1+WP2+WP3 adequately treated and interpreted in order to achieve Project Conclusions. Final Technical Report shall also include suggestions and recommendation for sustainable management of groundwater resources in southern Belize and proposal of monitoring providing critical data about system behavior throughout the monitoring network.

Project schedule

An overview of the Project schedule incorporating the key activities is shown in Tab. 1.

Tab. 1 Project schedule.

WP	Activity	From	To
WP1:	**Hydrogeological assessment**	**4.11.2013**	**4.8.2014**
WP1a	**Data acquisition and analysis**	**4.11.2013**	**5.12.2013**
	Review of available documentation based on public sources + communication with local agencies (topography,land use, roads and communications, vegetation, meteorology, hydrology, hydrogeology, geology, geophysics, water management,..	4.11.2013	5.12.2013
	Initial field survey - verification of existing wells/boreholes, initial groundwater table level measurements	18.11.2013	5.12.2013
	Detailed work plan	18.11.2013	5.12.2013
WP1b	**Data management and synthesis - GIS database, statistics, geostatistics**	**9.12.2013**	**20.4.2014**
	Implementation of available shp. files into GIS, combination of different layers with delineation of the studied area, statistics of available data in terms of water facilities & hydrogeological parameters (where applicable)	9.12.2013	16.3.2014
	Definition of well test program on newly drilled wells	24.2.2014	9.3.2014
	Identification of complex relationships and interactions of various components of geo-hydrological environment	10.3.2014	20.4.2014
WP1c	**Groundwater modelling**	**21.4.2014**	**4.8.2014**
	Formulation of conceptual model of hydrogeological structures of the Savannah Groundwater Province	21.4.2014	18.5.2014
	Model calculation using MODFLOW simulation package, simulation of proposed scenarios of development in groundwater management reflecting growing population centres and large expansion in tourism, aquaculture and agriculture	19.5.2014	4.8.2014
WP2:	**Field work**	**20.1.2014**	**6.4.2014**
WP2a	**Field work - stage 1**	**20.1.2014**	**16.2.2014**
	Mapping, verification of the geological and hydrogeological data	20.1.2014	9.2.2014
	Groundwater and surface water sampling (analyses will be subject of subcontracting of accredited laboratories)	27.1.2014	16.2.2014
	Measurements of existing wells	27.1.2014	16.2.2014
	Proposal of location and design of new wells to be drilled	27.1.2014	9.2.2014
	Supervision of initial drilling (drilling will be subject of subcontracting in WP3)	3.2.2014	16.2.2014
WP2b	**Field work - stage 2**	**10.3.2014**	**6.4.2014**
	Supervision of drilling (drilling will be subject of subcontracting in WP3)	10.3.2014	30.3.2014
	Execution and/or supervision of pump tests	10.3.2014	6.4.2014
	Additional water sampling	24.3.2014	6.4.2014
WP3:	**Drilling**	**3.2.2014**	**30.3.2014**
	Reporting, Conclusions	**22.7.2014**	**18.8.2014**

For WP description see section 4.2. Assessment Methodology.

5. Site Description – Review of documentation

This section provides description of the physiographic features of the Savannah Groundwater Province such as land use, climate, geological and hydrogeological setting. Information presented in this section is based on published reports, available web pages and past investigations conducted in southern Belize. All information is properly cited and citations are listed in the reference list of this Report.

5.1. Geomorphological setting

The Savannah Groundwater Province lies on the coastal plain in foreland of the Maya mountains. The area is rather flat with few small hummocks. The altitude typically ranges between 20 to 60 m a.s.l. On the slopes of the Maya mountains the altitude comes up to 500 m a.s.l. and steeper slopes is common.

Geomorphological setting, as displayed in Annex 2 clearly suggests delineation of the investigated area.

5.2. Land Use

Belize boasts the highest overall percentage of *forest cover* of any of the Central American countries (Vreugdenhil et al., 2002). Although, Belize has approximately 63% of the total land area under some form of forest cover, only about 14% of the forests (about 303,000 hectares) are available or appropriate for sustainable forest management for timber production.

In terms of Belize's *mangrove cover* - which assumes the form not only of mangrove 'forest' but also of scrubs and savannas, among others, was reported to be 3.4% of land cover (78,133 ha) (UNEP, 2011).

Belizean land is considerably used for *agriculture* providing roughly 65% of the country's total foreign exchange earnings. Over the last several years agriculture had been one of the most dominant sector contributing to the economic development of Belize. Nowadays, agriculture is second largest industry. Next to the transport sector, the agriculture sector is the second largest importer and user of chemicals in Belize (pesticides and fertilizers) and its related production and processing activities are the largest generators of industrial effluent and solid waste. Irrigation in Belize has been marginal because of its climatic and social conditions. Surface and sprinkler irrigation is being used for citrus and banana production, and surface irrigation is also used for rice and micro-irrigation of papaya production. It is expected that in the coming years more banana plantations will be irrigated where the estimated water withdrawal may be in the order of 240,000 m^3/yr (http://www.wikipedia.com). All of the irrigation systems in Belize are private and were developed with private funds or loans from international cooperation organizations such as the European Union (EU) (Ballestero, 2007).

In addition, aquaculture, in particular shrimp farming, is a growing threat to coastal ecosystems. Nutrient pollution, physical alteration of habitat, such as the destruction of mangrove forests, and sedimentation are all impacts of aquaculture experienced in Belize's coastal areas (UNEP, 2011).
Agriculture employs approximately 30% of the total labor forces. About 38% of the total land area is potentially suitable for agriculture use but only perhaps 10 – 15% is used. However, the potential for agricultural potential is not unlimited. The dominant sector in agriculture is sugar industry; other important agriculture sectors are citrus industry, banana farms and cacao – which becoming increasingly important as an export crop (http://ambergriscaye.com/pages/town/factsbze.html). As reviewed, the Savannah Groundwater Province covers 12 aquaculture farms and processing facilities, citrus farms (100 km^2) and banana farms (90 km^2) (Williams, 2011).

See Annex 3 for land use pattern in Savannah Groundwater Province.

Tab. 2 Land cover distribution in Belize (*http://www4.ncsu.edu/~cnjenki2/docs/Giri_and_Jenkins_2005.pdf*)

Forest	62,5 %
Shrubland	11,9 %
Grassland	5,1 %

Cropland	18,3 %
Barren land	1,9 %
Water bodies	0,3 %
Urban areas	0,1 %

5.3. Climate
Belize lies in the outer tropics or subtropical geographic area with mean monthly minima from 61° F (16° C) to 63° F (17° C) in winter and from 75° F (24° C) to 77° F (25° C) in summer and mean monthly maxima range from 82° F (28° C) in winter to 91°F (33°C) in summer.

Belize lies directly in the path of tropical storms and hurricanes and they are a consistent occurrence that bring heavy rainfall that challenge flood control management policies and infrastructure. Approximately 62% of the populated settlements in Belize lie within areas at high risk of flooding and many of these are located directly within flood plains that are inundated on an annual basis. The Belize *National Emergency Management Organization* (NEMO) handles the procedures that are needed during flooding events (http://www.wikipedia.com).

The on-shore breeze moderates the daily high temperature. The Belize coastal area is exposed to southeast trade-winds which attain greatest constancy in July. The northern coastal plain of Belize receives about thirty percent of the rainfall of southern Toledo district. Annual rainfall ranges from 1347 mm at Libertad (Corozal district) to 4526 mm at Barranco (Toledo district). Seasonal effects are more significant in the central and northern regions. In the south-central region the dry season lasts from February till April. A minor, less-rainy period usually occurs in August.

Two meteorological disturbances can alter typical weather patterns – those are northers and cyclones. Northers are cold, wet, northeast air masses occasionally pushed far to the south from November to February by arctic air masses. Local effects are cooler-than-normal temperatures, heavy rains and choppy seas. More dangerous are cyclones - non-frontal, low-pressure, large-scale systems that develop over tropical waters with a definite, organized circulation. Depending on wind speed and sustainability, cyclones are classified as tropical depressions, storms or hurricanes; hurricanes are the most powerful cyclones with minimum sustained winds of 119 km/hour (Hartshon G., 1984).

5.4. Geological setting
From the tectonic point of view, Belize is located near the junction of the North American and Caribbean tectonic plates (
Fig. 3), slabs of the earth's crust that have moved past each other over the last 80 million years. Eastward drift of the Caribbean plate resulted in the dominantly structurally-controlled major features of Belize - the Maya Mountains (http://ambergriscaye.com/geology/).

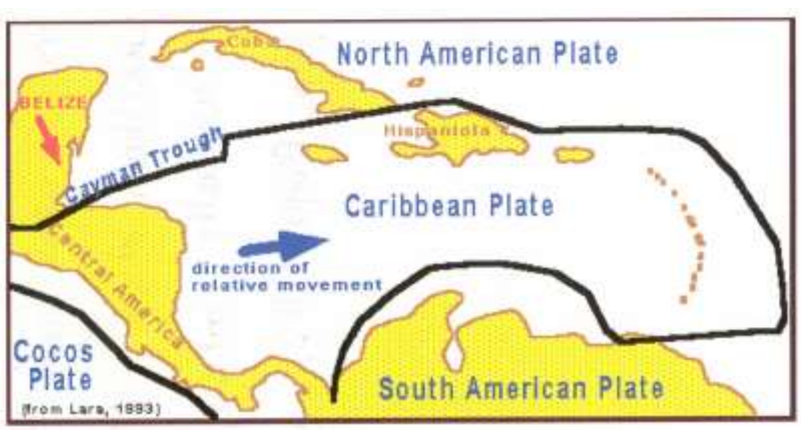

Fig. 3 Caribbean Plate (Aitken J. et Stewart R, 2002)

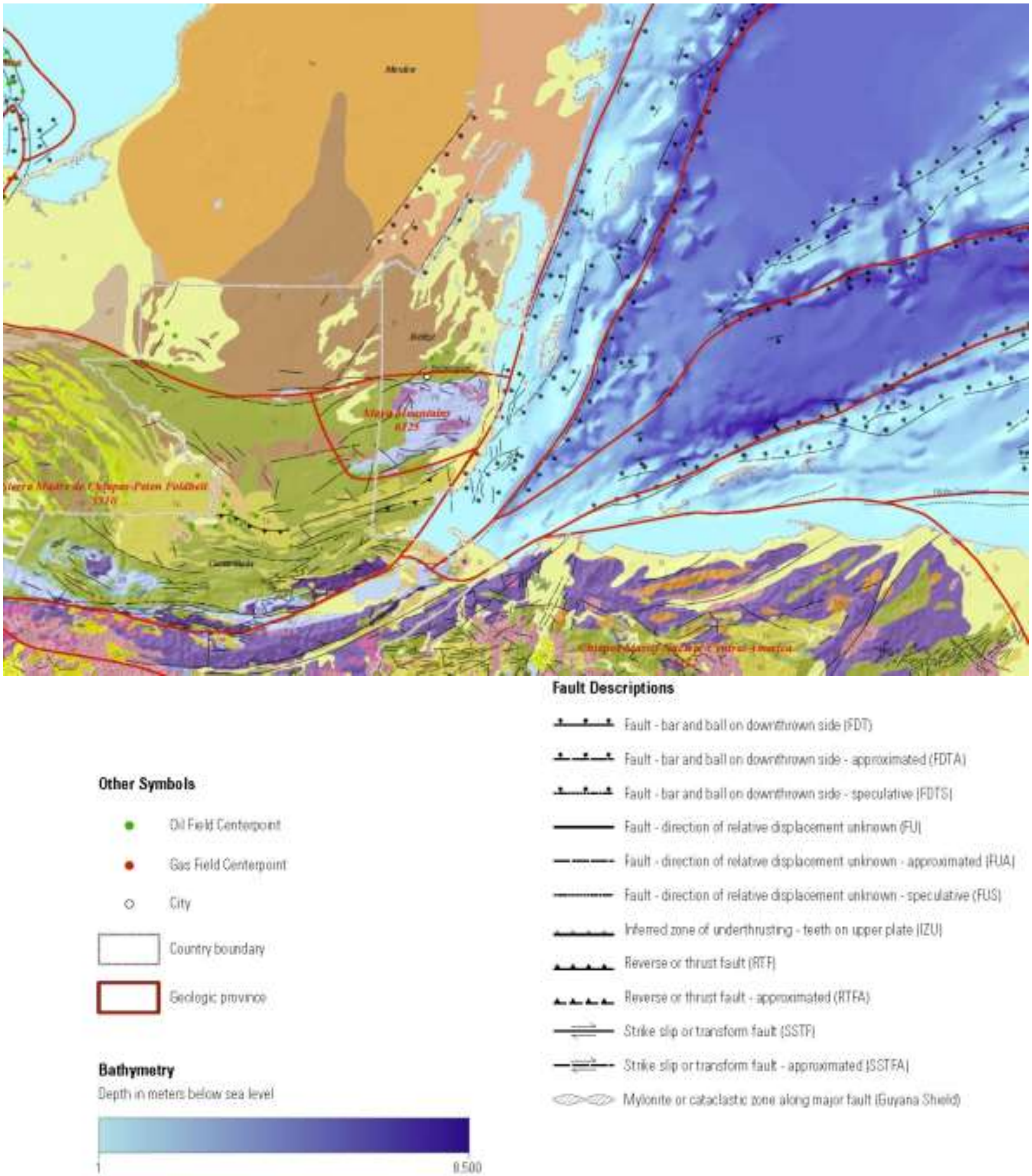

Fig. 4 Tectonics in broader area of Belize and surroundings (USGS).

Based on regional seismic activity, most of Belize is not known to be a tectonically active. However, the tectonics and faulting represent a significant feature of the studied regional groundwater structure.

Almost all the Savannah Groundwater Province is located on the Coastal Plain (Annex 4). Within the Coastal plain there are alluvial fans and relict marine terraces. These are pleistocene sediments overlain by more recent floodplains and terraces of the Toledo Flood Plains Land System. The quaternary alluvium deposited in the terrestrial zone is poorly consolidated and readily erodible. This could be a major source of sediment influx to the lagoon especially in case of changing land use, deforestation and desertification (Ariola, 2003).

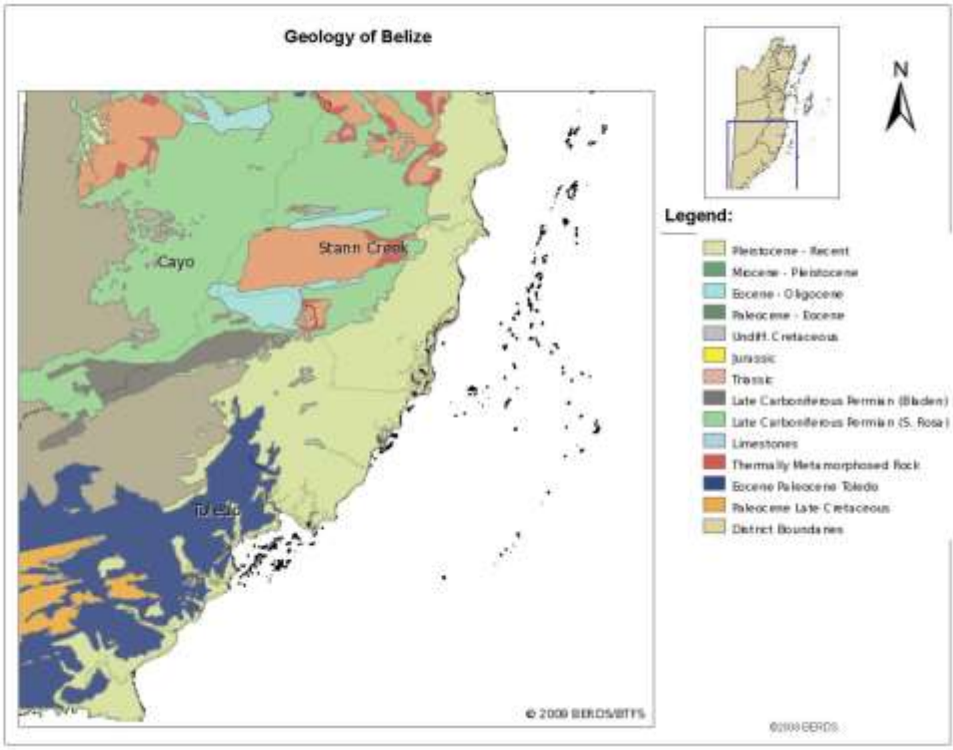

Fig. 5 Geology of southern Belize (*http://www.biodiversity.bz*)

5.5. Hydrological setting

Belize hydrology network is divided to major river catchments and sub-catchments. The Savannah Province is located in the Southeastern watershed region (Boles, 1999). In total 19 watersheds are included in the investigated area (Tab. 3, Annex 5, Annex 6):

Tab. 3 List of Watersheds in Savannah Groundwater Province

North Stann Creek
Bocatora Creek
Yemeri Creek
Northern and Southern Lagoon
Black Creek
Mullins River
Sennis River
Big Creek
Mango Creek
Freshwater Creek
Punta Ycacos Lagoon
Monkey River
Pine Ridge Creek
Sittee River
Santa Maria Creek
South Stann Creek
Golden Stream

Deep River
Cabbage Haul Creek

Main rivers are represented by North and South Stann Creek, Sittee River and Monkey River with its tributaries Swasey and Bladen. All streams are draining southeastern and eastern slopes of the Maya mountains. In the mountainous areas they have well developed branching pattern with relatively steep, straight courses. Below the slopes on the coastal plain, streams become more sluggish and drainage of the area is less effective (Hartshorn et al., 1984).

Rivers are generally discharged into the Caribbean Sea. The flow rate varies depending on the rain season. Many streams do not exist during dry season. Some of streams are equipped by gauging stations, such as Melinda Forest Station on the North Stann Creek, Kendall Bridge on the Sittee River, South Stann Creek station, Swasey Bridge on the Swasey River and Bladen Bridge on the Bladen River.

Tab. 4 Major rivers in Savannah Province
(http://www.bvsde.paho.org/muwww/fulltext/analisis/belice/Belice01.html)

	drainage area (km^2)	**Discharge (m^3/s)**
North Stann Creek	281,4	15
Sittee River	451,2	14
South Stann Creek	258	9
Monkey River	1.275,40	35-40

Being a part of a coastal plain, Savannah Province is rich in lagoons, mangrove swamps, deep estuaries and river-mouth bars (Hartshorn et al., 1984). Water from rivers is commonly used as a reliable water source. Surface water is generally suitable for irrigation purposes but in some places is used as drinking water source as well.

5.6. Hydrogeological setting

The Savannah groundwater province extends over an area approximately 1500 km^2 (Williams, 2011) in southeastern part of Belize, in the Stann Creek district and partly in the Toledo district. Estimated boundaries of province were delineated by Jean Cornec, however no real field mapping of the area was done.

The aquifers in the northern portions of this Province are confined and overlain with karstic and fractured cretaceous limestones and quaternary alluvial deposits.

Multiple aquifers exist within this Groundwater Savannah Province with the alluvium deposits forming the uppermost or phreatic aquifers. These phreatic aquifers found 3 to 8 m below the surface are discontinuous and connected to rivers and streams extend westward and pinches out near the 40-metre contour. Immediate aquifer response can be expected to pumping, drought, and rainfall.

A second and lower 20 m thick aquifer exists near 25 m. Like the phreatic aquifers it extends westward up the slopes of the Maya mountains and pinches out near the 100-metre contour. This aquifer consists of primarily calcareous sandstone. This aquifer is confined by a clay aquiclude that pinches out westward below the 100 m contour. It transcends the entire areal extent of the Province. The recharge is from rainfall in the vicinity of the exposed sandstone contact with the Maya Mountains. Wells tapping this Province penetrate to depths less than 65 m with depths to water ranging from 8 to 33 m. The potentiometric surface for this aquifer ranges from 2 to 8 m below the surface depending on the surface features (TNCE, 2006).

The width of the recharge area was mapped to be above the western extent of the phreatic aquifers 60-metre contour and the western extent of the province. Estimated area is 418 km^2 (Williams, 2011).

In 2006, in the frame of the Project „Future Solutions for Today's Water Challenges" related to proposed Ara Macao residential and commercial project aquifer and pumping tests were conducted. The investigated site, Ara Macao, lies approximately half mile from Riversdale Village at the top of the Placencia Peninsula, approximately in the middle of the Groundwater Savannah Province.

These tests were conducted to determine the capacity of the perforated well 1A. It was also conducted to determine the aquifer properties such as the Transmissivity and Storativity of the Savannah Groundwater Province in the region of the Ara Macao development (TNCE, 2006).

Fig. 6. Ara Macao well pumping and monitoring location in the scope of the Project "Future Solutions for Today's Water Challenges" (TNCE, 2006).

WELL LOCATION					
ID	E	N	STATIC LEVEL	WELL DEPTH	COMMENTS
WELL 1A	358980	1845417	3.55 ft	125 ft	Well to be pumped (see project well section)
WELL 1B	358989	1845388	3.9 ft	65 ft	Well to be monitored
WELL 2	357195	1846847	N/a	N/a	Three wells located in Sagitun Compound (one to be monitored)
WELL 3	356635	1843367	7.5 ft	67 ft	6 "Pvc Casing in Nova Shrimp farm (to be monitored)

The Ara Macao wells are within the northern portions of the Savannah Groundwater Province of Belize and tap a 18.29 m (60 ft) aquifer confined by a 9.14 (30ft) clay aquiclude that is overlain with karstic and fractured cretaceous limestones and quaternary alluvial deposits. Aquifer test indicate that the transmissivity of the pumped aquifers is 1.541 m^2/day. The storativity of the aquifer was calculated to be1.82 * 10^{-4} and the hydraulic conductivity 3.72 * 10^{-1} m/day.

6. Conclusions

The inception stage of work on the groundwater assessment Savannah Province presented in the Inception Report has focused on

- review of data and information available from open sources;
- identification of features and boundary conditions of the studied groundwater structures;
- review and further elaboration of applied methodology as well as of detailed technical plan of work.

No major risk or threats for the project completion have been identified.

The available data enable to efficiently start the field work within first weeks of the year 2014 to validate and further extent the knowledge of groundwater regime in the Savannah Province.

The office work shall focus on data integration and development of advanced GIS-based database. Data synthesis shall be carried out by numerical groundwater simulation to quantify hydrogeological characteristics of the Savannah Province for efficient groundwater management and protection.

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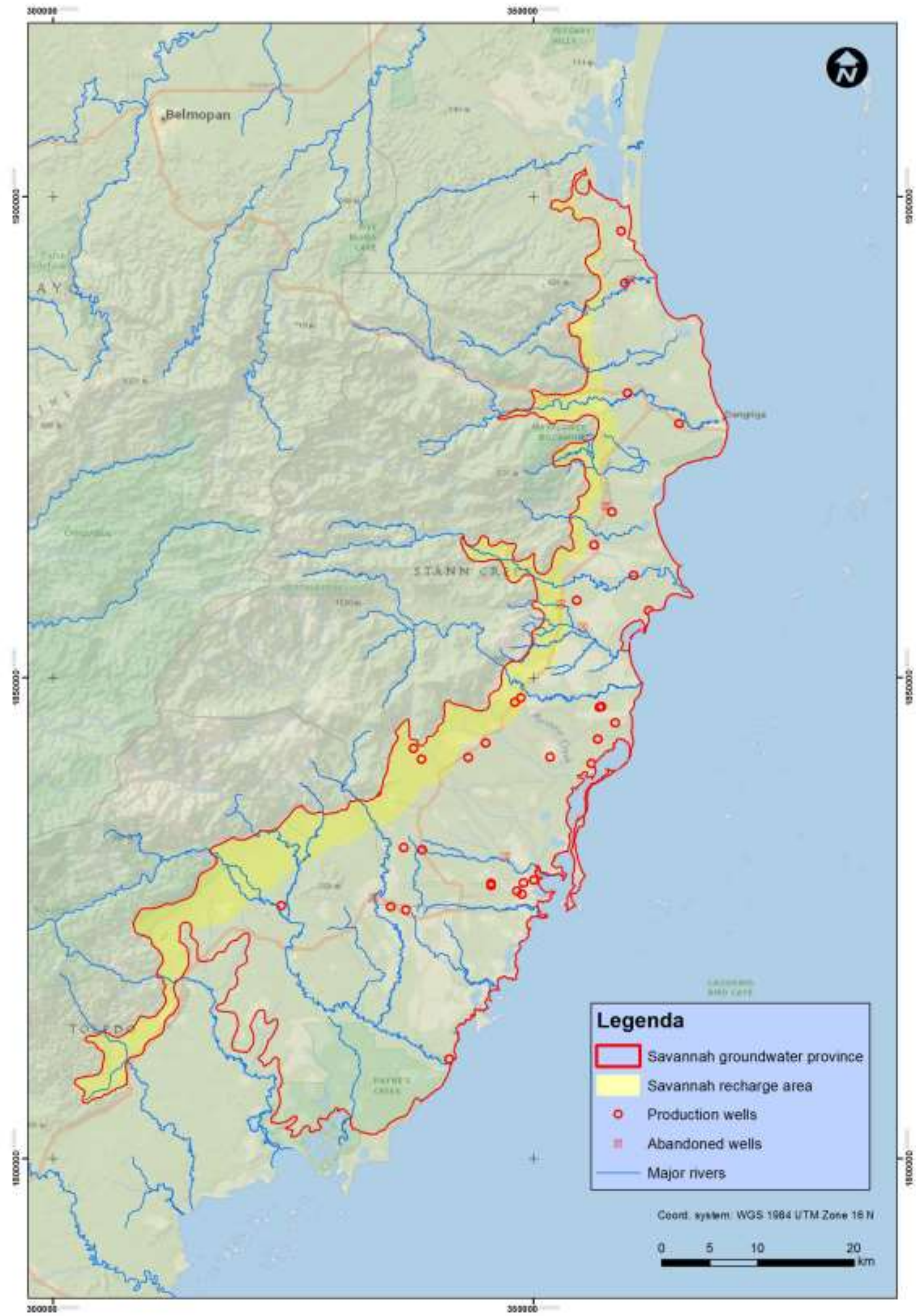
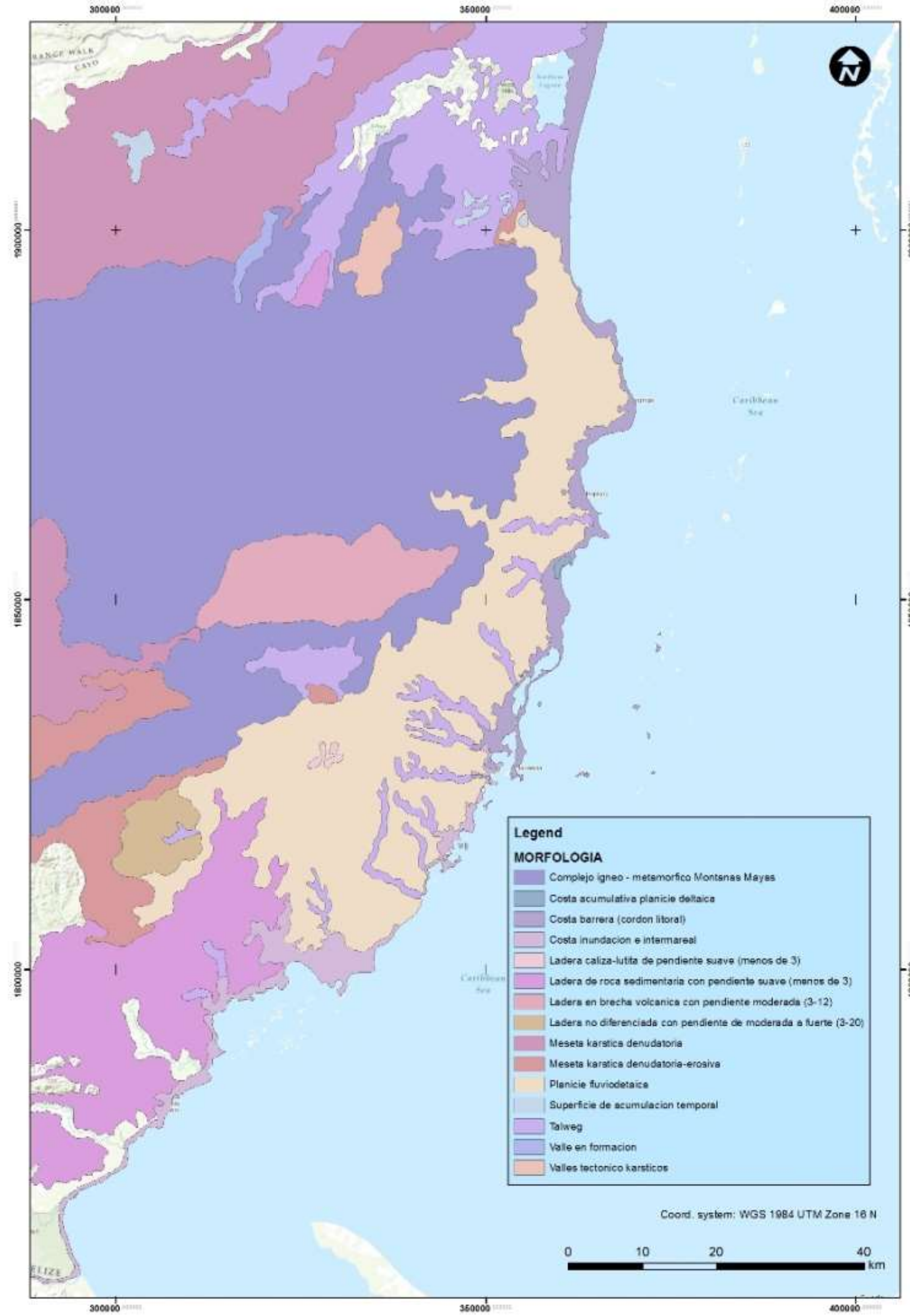
Annexes

- Annex 1 Production and abandoned wells in Savannah Groundwater Province.
- Annex 2 Geomorphology of southern Belize delineating the Savannah Groundwater Province.
- Annex 3 Landuse of the Savannah Groundwater Province.
- Annex 4 Simplified geology of the Savannah Groundwater Province.
- Annex 5 Watersheds in the Savannah Groundwater Province.
- Annex 6 Distribution of existing wells within the Savannah Groundwater Province watersheds.

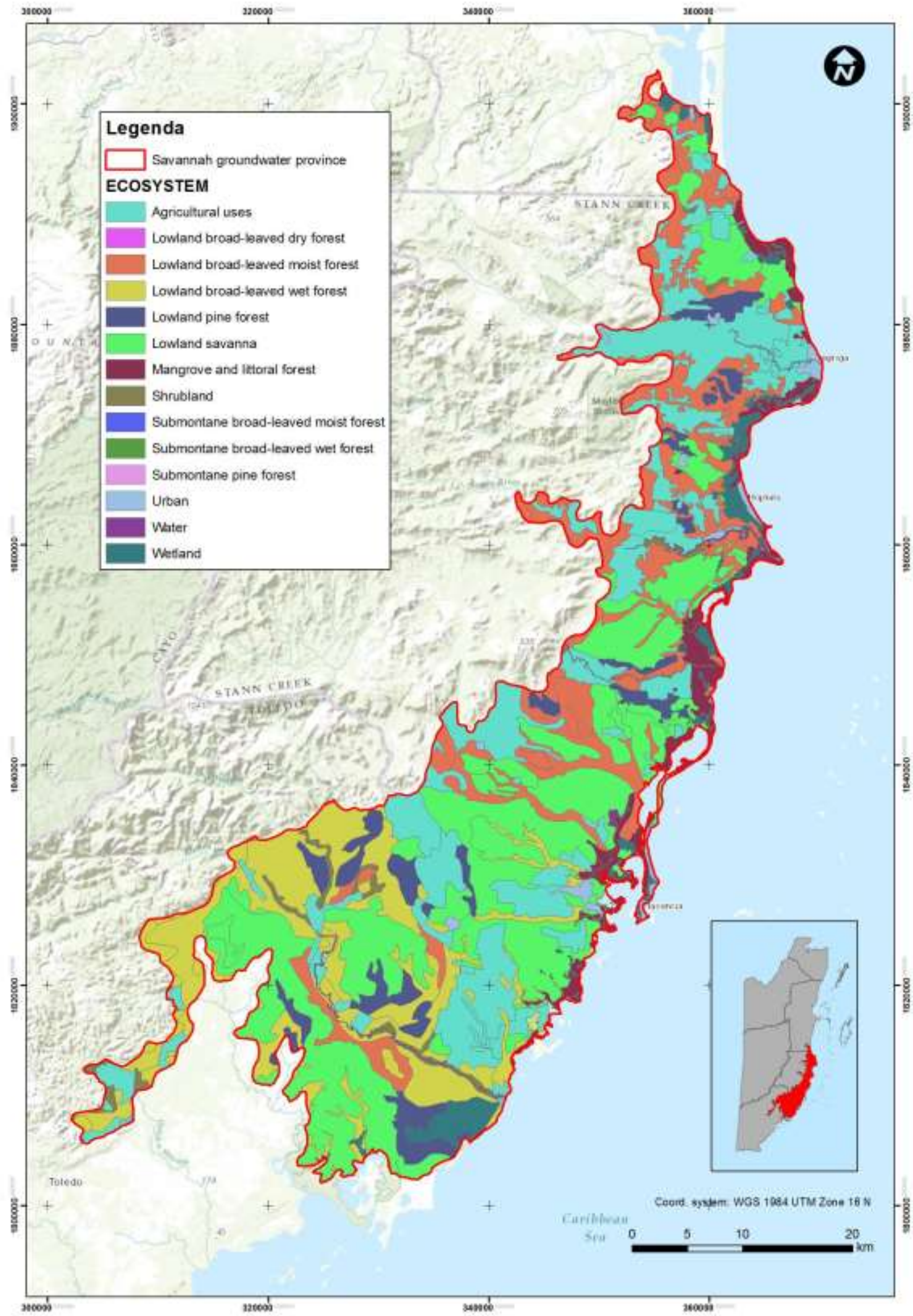
Annex 1 Production and abandoned wells in Savannah Groundwater Province.



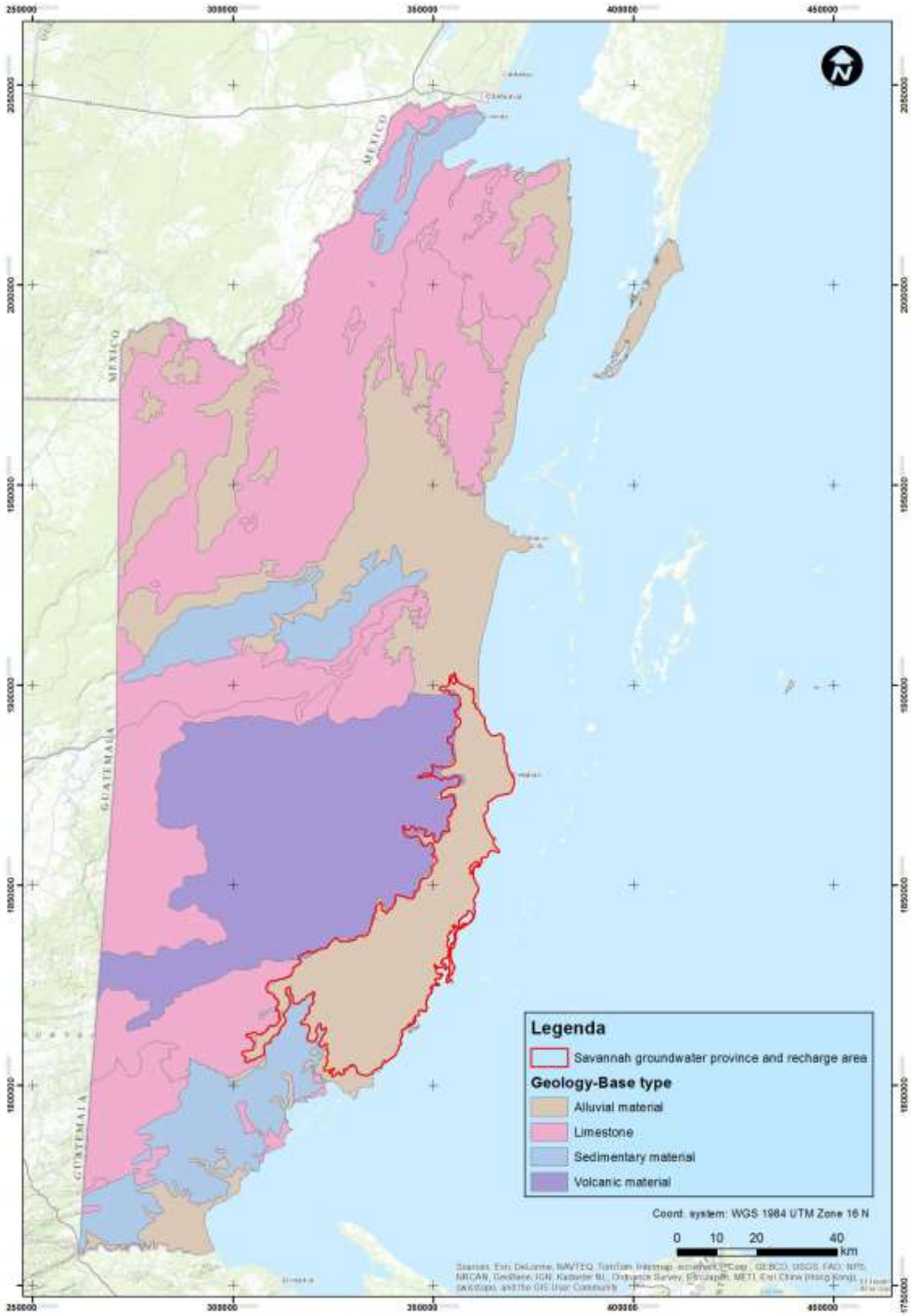
Annex 2 Geomorphology of southern Belize delineating the Savannah Groundwater Province.



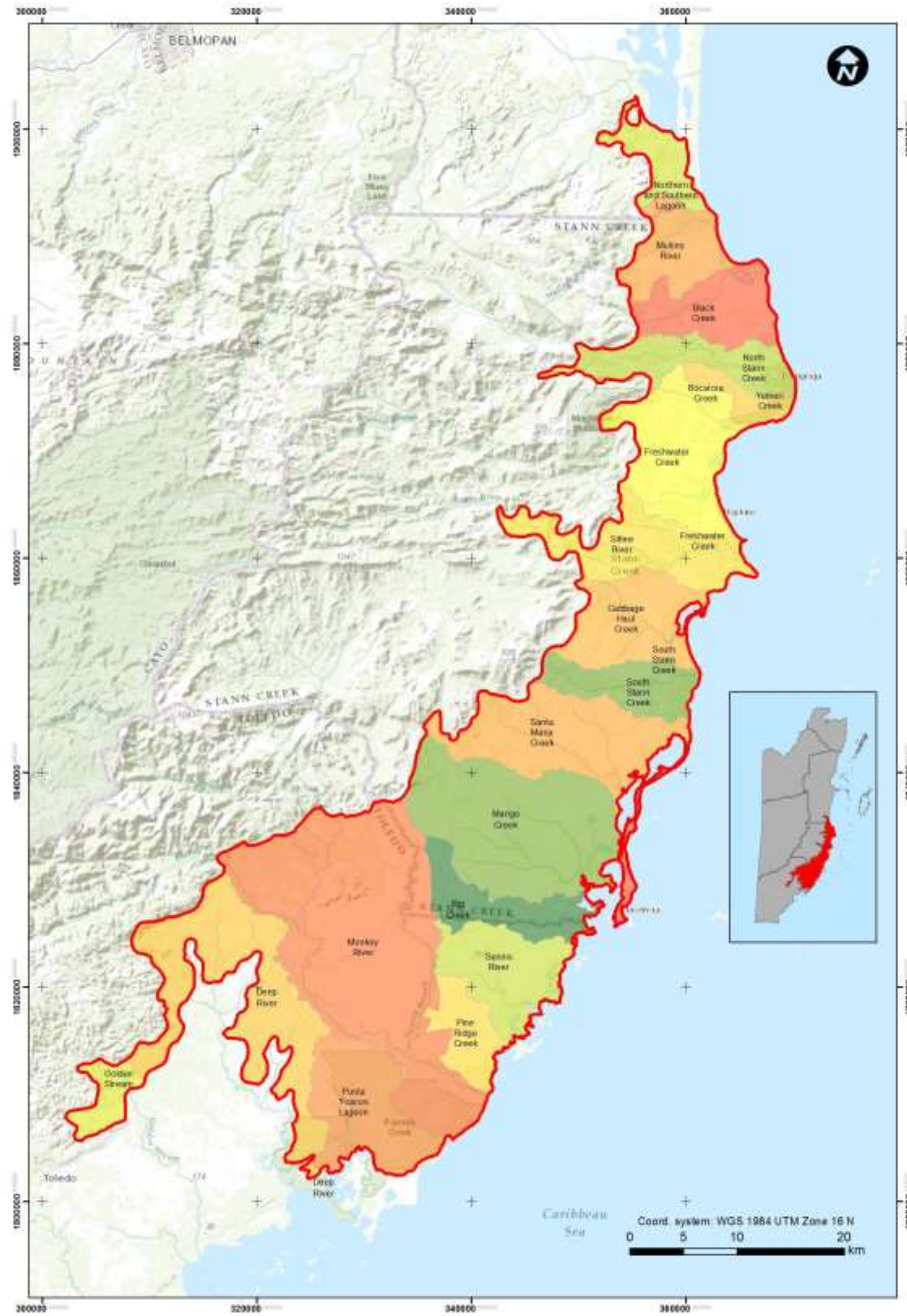
Annex 3 Land use of the Savannah Groundwater Province.



Annex 4 Simplified geology of the Savannah Groundwater Province.



Annex 5 Watersheds in the Savannah Groundwater Province.



Annex 6 Distribution of existing wells within the Savannah Groundwater Province watersheds.