CHARACTERIZATION OF THE INFLUENCE AREA

B	16/10/2015	Abiotic characterization	Luisa Alzate, Marlon Agamez, Juan Salazar, Julio Mesa	Carlos Rey, July Bibiana Salazar	Maria Andrea Patiño
REVIEW	**DATE**	**DESCRIPTION**	**MADE BY**	**REVIEWD BY**	**APPROVED BY**

Review A: Issued for Customer Comments
Review B: Issued for Customer Approval
Review 0: Approved for Basic Engineering

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Físicos	Temperatura (°C)	23,4	24,3	24,1	24,2	24	23,7	23,6	24,6	24,1	23,9	24	24,1	-	-
	Potencial de Hidrogeno - pH	8,13	8,15	8,34	8,49	7,92	8,34	8,36	6,56	6,28	8,16	8,28	8,35	-	-
Químicos	Grasas y aceites (mg/kg)	525	386	510	514	546	925	891	676	533	1064	432	<200	-	-
	Arsénico (mg/kg)	4,6	4,4	5	4,6	4,6	5	5,6	6	4,2	4,8	3	4,6	80,00	200,00
	Bario (mg/kg)	24,3	25,1	<23,0	<23,0	59,8	<23.0	24,8	52,2	73,1	<23.0	<23.0	<23.0	-	-
	Cadmio (mg/kg)	<7.72	<7.72	<7,72	<7,72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	1,00	5,00
	Zinc (mg/kg)	36	32	32	32	38	42	30	32	32	30	32	34	500,00	3000,00
	Cromo (mg/kg)	56	52	66	60	58	66	144	56	48	64	50	60	200,00	1000,00
	Cromo hexavalente (mg/kg)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	-	-
	Cobre (mg/kg)	63,7	73,8	68,1	59,3	61,4	59,5	66,1	46,1	<27.5	66,9	62,3	31,3	100,00	400,00
	Mercurio (mg/kg)	2	<1.8	1,8	<1.8	3,2	<1.8	2,2	<1.8	<1.8	2	<1.8	<1.8	0,60	3,00
	Niquel (mg/kg)	56	60	66	64	60	66	70	56	54	64	46	66	100,00	400,00
	Plomo (mg/kg)	24	20	28	24	20	36	32	32	<20	32	22	26	120,00	600,00
	Selenio (mg/kg)	0,15	0,161	0,147	0,132	0,152	0,136	0,142	0,155	0,153	0,133	0,136	0,141	-	-
	Hidrocarburos Totales %	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	-	-
	Fenoles (mg/kg)	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	-	-
	HAP's (mg/kg)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	-	-
	Carbono Orgánico Total (mg/kg)	22545	35121	31069	28832	19713	24001	24046	24341	15676	23469	15789	22612	-	-
	Fósforo Total (mg/kg)	<1.50	<1.50	3,51	1,68	2,16	5,81	7,95	1,68	2	5,02	6,6	8,79	-	-
	Nitrógeno Total (mg/kg)	1543,13	1480,86	1789	2840,62	1623,97	1309,67	1965,04	1366	1497,27	1390,47	2717,91	4385,62	-	-
	Sulfuro Ácido Volátil (SAV) (%P/P)			9,26		7,52	2,15			6,90	1,00			-	-

TABLA ESTADISTICOS BÁSICOS

Variable medida:Hs

direcciones(°)	prob.direccion	$Hs_{50\%}$	$Hs_{10\%}$	$Hs_{25\%}$	$Hs_{05\%}$	$Hs_{1/250\,(50\%)}$
ESC	——	0.9600	1.9500	2.1900	2.6600	3.1732
N	0.0208	0.9200	1.8400	2.2800	2.9138	3.3916
NNE	0.7697	1.1400	2.0300	2.2600	2.7100	3.2272
NE	0.1091	0.4300	0.7000	0.7700	0.9500	1.1131
ENE	0.0000	0.5400	0.6700	0.6700	0.6700	0.6700
E	0.0000	0.7000	0.7000	0.7000	0.7000	0.7000
ESE	0.0000	0.4500	0.4500	0.4500	0.4500	0.4500
SE	0.0001	0.4000	1.1700	1.1700	1.1700	1.1700
SSE	0.0008	0.6700	0.9700	1.0725	1.1200	1.1200
S	0.0084	0.6100	0.9200	1.0470	1.1594	1.3300
SSW	0.0176	0.6400	0.9300	1.0120	1.1600	1.3191
SW	0.0147	0.6200	0.9000	0.9800	1.1104	1.2616
WSW	0.0052	0.5150	0.8630	0.9440	1.1684	1.1900
W	0.0012	0.5000	0.9500	0.9990	1.2494	1.2500
WNW	0.0031	0.2400	0.7000	0.8070	1.1240	1.2900
NW	0.0109	0.5600	1.1440	1.5100	2.1778	2.8964
NNW	0.0275	0.6100	1.5890	2.0920	2.7704	2.9890

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Map Code	Thematic
MOD_LA_PTO_ANT_06_Geologia	Geology
MOD_LA_PTO_ANT_07_Geomorphology	Geomorphological units
MOD_LA_PTO_ANT_08_ Morphodynamics	Morph dynamics
MOD_LA_PTO_ANT_09_ Susceptibility	Erosive processes susceptibility
MOD_LA_PTO_ANT_10_MDT	Digital terrain model
MOD_LA_PTO_ANT_11_ Landscape	Landscape Unit
MOD_LA_PTO_ANT_13_ Visibility	Landscape Visibility
MOD_LA_PTO_ANT_12_ QualityLandscape	Visual Quality of the Landscape
MOD_LA_PTO_ANT_14_Soils	Soil Cartographic Units
MOD_LA_PTO_ANT_15_PotentialUse	Potential Use of Soil
MOD_LA_PTO_ANT_16_CurrentUsage	Current Land Usage
MOD_LA_PTO_ANT_17_UsageConflict	Land Usage Conflict
MOD_LA_PTO_ANT_18_Hydrology	Hydrology
MOD_LA_PTO_ANT_19_WaterSediment	Water and sediment quality Sampling
MOD_LA_PTO_ANT_20_Hydrogeology	Hydrogeology
MOD_LA_PTO_ANT_21_WaveBottom_I	Waves Bottom - Initial condition - Case 2
MOD_LA_PTO_ANT_22_ WavesBottom _F	Waves Bottom - Initial condition - Case 2ª
MOD_LA_PTO_ANT_23_LocalWaves_I	Local waves – Initial condition - Case 4
MOD_LA_PTO_ANT_24_ LocalWaves _F	Local waves - Final condition- Case 4a
MOD_LA_PTO_ANT_25_StreamsI	Streams due to breakage of the Local waves - Initial Condition
MOD_LA_PTO_ANT_26_SteamsF	Streams due to breakage of the Local waves - Final Condition
MOD_LA_PTO_ANT_27_ Geotechnics	Geotechnics
MOD_LA_PTO_ANT_28_AirNoise	Air quality and environmental noise Monitoring
MOD_LA_PTO_ANT_29_NoiseE1_D	Noise modeling - Scenario 1 Daytime Isofones
MOD_LA_PTO_ANT_30_NoiseE1_N	Noise modeling - Scenario 1 Night Isofones

MOD_LA_PTO_ANT_31_NoiseE2_D	Noise modeling - Scenario 2 Daytime Isofones
MOD_LA_PTO_ANT_32_NoiseE2_N	Noise modeling - Scenario 1 Night Isofones
MOD_LA_PTO_ANT_33_Ecosistema	Onshore, coastal and offshore ecosystems

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Attachment 5.1.1 Water quality and sediments

Attachment 5.1.2 Geotechnics Final Report

Attachment 5.1.3 Transit_Study_Puerto Antioquia

Attachment 5.1.4 Air quality and noise

5. CHARACTERIZATION OF THE INFLUENCE AREA

This chapter presents the characterization of the abiotic, biotic and socioeconomic environment of the area of influence of the project, in accordance with the terms of reference for the research of the Environmental Impact Study - EIA in construction or expansion and operation projects. of maritime ports of great depth (MM-INA-05), the Methodology for the environmental studies presentation (MAVDT, 2010) and the Manual of environmental evaluation of the Environment and Sustainable Development Ministry – (Also known as MADS).

5.1 Abiotic environment

The following are the results of the abiotic environment characterization for each of the components that make up the environment in accordance with the specific methodologies of each of the disciplines, which were described in Chapter 2 Generalities, with the aim of obtain a baseline of the influence area of the project.

5.1.1 Geology

The geological characteristics play an important role in the potential uses of the territory since it is determinant in the types of soils, the natural threats that may arise, the mineral resources and the morphology of the region.

In this chapter, a description of the predominant types of rock at the regional and local levels is given, as well as their spatial disposition and the structural features, while in Figure No. 5.1 and on the geological map MOD_LA_PTO_ANT_06_Geology, their spatial dispositions are presented.

- *Regional Geology*[1]

The research area is located in the part of the Colombian Caribbean that corresponds to a plate margin basin, of Cenozoic age, structured in two adjacent belts or folded belts, the San Jacinto Folding Belt accreted to the North margin of Colombia in the Paleogene and the Sinú Folded Belt, which seems to have been emplaced along the western margin of the San Jacinto Belt and its probable age is neogenic. Most of the San Jacinto belt emerges offshore, the northern portion is under the sea. The southern portion of the Sinú Belt surfaces offshore, while two thirds of the belt are offshore. Sinú belt rocks are mostly from the Miocene to the Recent, according to

[1] NATIONAL HYDROCARBONS AGENCY -ANH. Geological Cartography and Structural Modeling of the Urabá and Sinú-San Jacinto Basins based on the Interpretation of Remote Sensing Images and Seismic Monitoring. 2009

Duque-Caro[2], Due to these characteristics, it is considered that the belt of Sinú corresponds to a later phase of accretion of oceanic crust that continues today and whose most representative feature is the presence of intense diapirism and mud volcanism[3].

The morphological expression of the Sinú Folded Belt is less prominent than that of San Jacinto. In the Sinú Folded Belt, as well as in the southern and northern culmination of the San Jacinto Belt, large synclinals are developed in relation to the greater thrusts; these structures, by their characteristics, represent longitudinal sinking basins[4].

The western flank of the study area is located in the northern department of Choco, it is known as the Urabá Chocoano and comprises from south to north from Cerro El Cuchillo, on the border between the departments of Chocó and Antioquia, to the municipality of Acandí, that in the work of Geotec[5] It is known as the Baudó volcanic complex, but for its description the formal units of the complex of Santa Cecilia - La Equis and Batolito de Mande are used, which are part of a volcanic arch called Sutata Arch, Dabeiba Arch or Mandé Arch, located in a cot area[6].

- Lithology

The lithological description that is made below is taken from the municipal POT, the descriptions of the lithological units will be related to the geomorphological Macro units.

- **Lithology in the geomorphological macro-state of Mountain range and Foothills:**

Sedimentary Tertiary rocks of marine origin (T1)[7]

This unit emerges to the East of the Municipality. Its deposit environment is marine. According to the places mapped by INGEOMINAS (now Colombian Geological

[2] DUQUE-CARO, H. Geotectonics and evolution of the Colombian Northwest Region Geological Bulletin. INGEOMINAS, Volume 23, No.3. Bogotá.1978
[3] GUZMAN G, GÖMEZ., E., L., SERRANO, B., E. Geology of the Belts of Sinú, San Jacinto, and Western Edge of the Lower Magdalena Valley. Scale 1: 300,000. INGEOMINAS.2004
[4] GEOTEC. Geology of the Sinu-San Jacinto Belt Plates 1100.000: 50 Puerto Escondido, 51 Lorica, 59 Mulatos, 60 Canaletes, 61 Montería, 69 Necoclí, 70 San Pedro de Uraba, 71 Planeta Rica, Turbo 70 and 80 Tierra Alta. Report I-20024. INGEOMINAS. 2003
[5] Ibíd.
[6] GONZALEZ, H. Geological Map of the Department of Antioquia. Explanatory Memory INGEOMINAS, Map scale 1: 400000. 2001
[7] COLOMBIAN GEOLOGICAL SERVICE -SGC (KNOWN BEFORE AS INGEOMINAS). Evaluation of groundwater in the Urabá region 1995

Service - SGC), it is composed of a sequence of sandstones, mudstones and arcillites, locally carbonated.

Sedimentary Tertiary rocks of Onshore origin (T2)[8]

The rocks found are sandstones, conglomerates, siltstones and arcillites, deposited in an Onshore environment of fluvial to transitional nature, in which medium to high energy regimes are alternated with periods of tranquility, the rocks of Pliocene to Upper Holocene age were grouped as the Corpa, Pajuil and Floresanto Formations in the following sets:

Sandstones and mudstones (T2A): Gray-yellow sandstones, with a thin to medium grain, composed of quartz, basalts, black chert, which are interbedded with layers of friable, pale blue-gray mudstone.

Sandstones and conglomerates (T2B): The sandstones have the same characteristics of the T2A set, with the difference that they are interbedded with conglomerate layers formed by quartz and basalts in a sandy matrix. The conglomerates are made up of fragments of quartz, chert and volcanic rock (basalts), in a grayish-yellow sand matrix, of medium to coarse grain.

Lodoliths with conglomerate lenses (T2C): Composed by discontinuous layers of blue-gray mudstone interspersed with discontinuous layers of conglomerates. This set emerges on the westernmost flank of the Abibe Mountain range, forming the low hills that lie along the Juradó-Turbo highway.

These units contain some areas (part of the lower part of Río Grande) with abundant organic matter and semi-processed shells for transport purposes.

- **Lithology in the geomorphological unit, alluvial plain and coastal complex:**

Quaternary sediments (Q)[9]

The quaternary in the municipality is composed of deposits of marine, alluvial or colluvial origin that make up fans, terraces, cones of dejection, alluviums and beaches, which are related to the dynamics of the main rivers and the great alluvial

[8] Ibíd.

[9] COLOMBIA.MUNICIPALITY OF TURBO. 2000. Op. Cit.

plain of Mutatá-Turbo. On these deposits are located the port project, the head and much of the plantain and banana crops of the Municipality.

In the fan area the slopes reach 10%. It is constituted in depth by sandstones and gravels of siltstone. Near the surface these materials have weathered to clays. In the Guadualito River basal materials consist of pebbles and gravels of well-cemented and rounded sandstones, wrapped in a matrix of fine sand[10].

According to the description of the lithological units, there are no quarries in the area near the project that can supply hard rocks (igneous, volcanic or metamorphic rocks), as the ones the project will require during the construction phase. The infrastructure projects that have been carried out in the area have obtained the materials of the Carepa and Currulao rivers and the construction materials of the lomerios system that are made up of sedimentary rocks (Unit T2), although from this last source the Sieve is smaller, reaching only average gravels.

- Structural features

The structural features are related to the deformations suffered by the rock strata product of efforts, movements or the form and environments of deposition (offshore, fluvial, lacustrine, etc.). The Urabá region and in general all of the Colombian North-West is subject to the effect of active faults (see Figure No. 5.1) and strong deformations due to the influence of at least three tectonic plates and two blocks: Nazca plate, Caribbean plate, South America plate, Panama block and Andean block[11].

The study area is framed regionally within the Sinú Belt, which includes Abibe's and Palomas anticlinoriums inside the onshore and the offshore platform as well as the onshore slope. This belt is made up of very pronounced narrow anticlines, separated by broad and smooth synclines. Towards the North these structures are generally cut by dome structures of mud volcanoes giving the impression that the folding had been formed by this type of events. Within this series of synclines and anticlines we can mention the Tulapa syncline and the Cayman anticline, located north-east and north of the municipal head of Turbo respectively, whose axes have a general direction of N-S ± 10 °.

Another type of structural feature are faults. One of the most outstanding, located east of the municipality of Turbo is the Apartadó Fault (regionally known as the

10 ORGANIZATION OF AMERICAN STATES. Darién Project: Study for the orientation of the integrated development of the Colombian Darién region, Medellín, 1978. 171p.
11 ESTRADA, B. E. Characterization studies of an earthquake-source according to its importance for the city of Medellin. Thesis work (Geological Engineering). National University. Faculty of Mines. Medellín, 1998, 139p.

Uramita fault), which is approximately 13 km east of the project (see Figure No. 5.1), presents a general address NS to N30W and dips to the east between 30 and 40º. This fault forms the contact between units T1 and T2 and extends from the south of Apartadó to near the mouth of the Caimán Viejo River. Given the deformations found in the influence area of the fault, concentration of small aligned movements, concentration of diaclases, topographic and drainage guidelines, there is a possibility that it may have recent activity, a situation that could represent a threat to the project due to the probable occurrence of a seismic event. The San José fault, to the east of this, is part of the same fault system[12].

There are also other faults and guidelines with a general direction N-S, which may have an influence on the municipality but on which no studies of neotectonics have been carried out that demonstrate its recent activity (in the last 30,000 years). This is the case of the San Pedro, Murrí-Mutatá, El Aguila and Murindó faults. The latter related to the earthquake that occurred in October 1992 within the municipality of the same name.

12 INSTITUTE OF REGIONAL STUDIES. Urabá development plan with emphasis on the environment. Medellín: University of Antioquia. 1994.

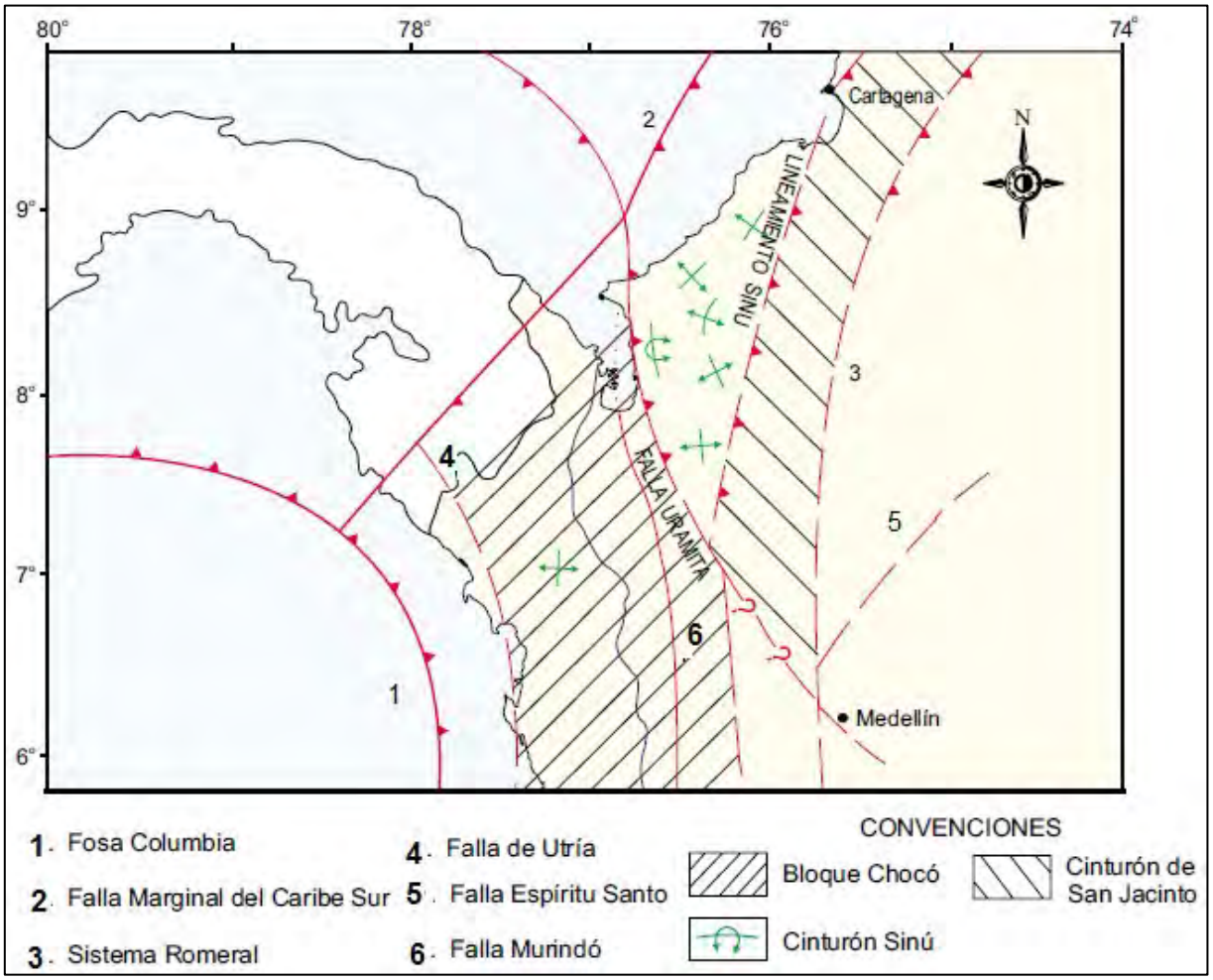

Figure No. 5.1 Geological structures of the Colombian NW
Source: Modified from GONZÁLEZ[13]

[13] GONZÁLEZ, 2001. Óp. Cit.

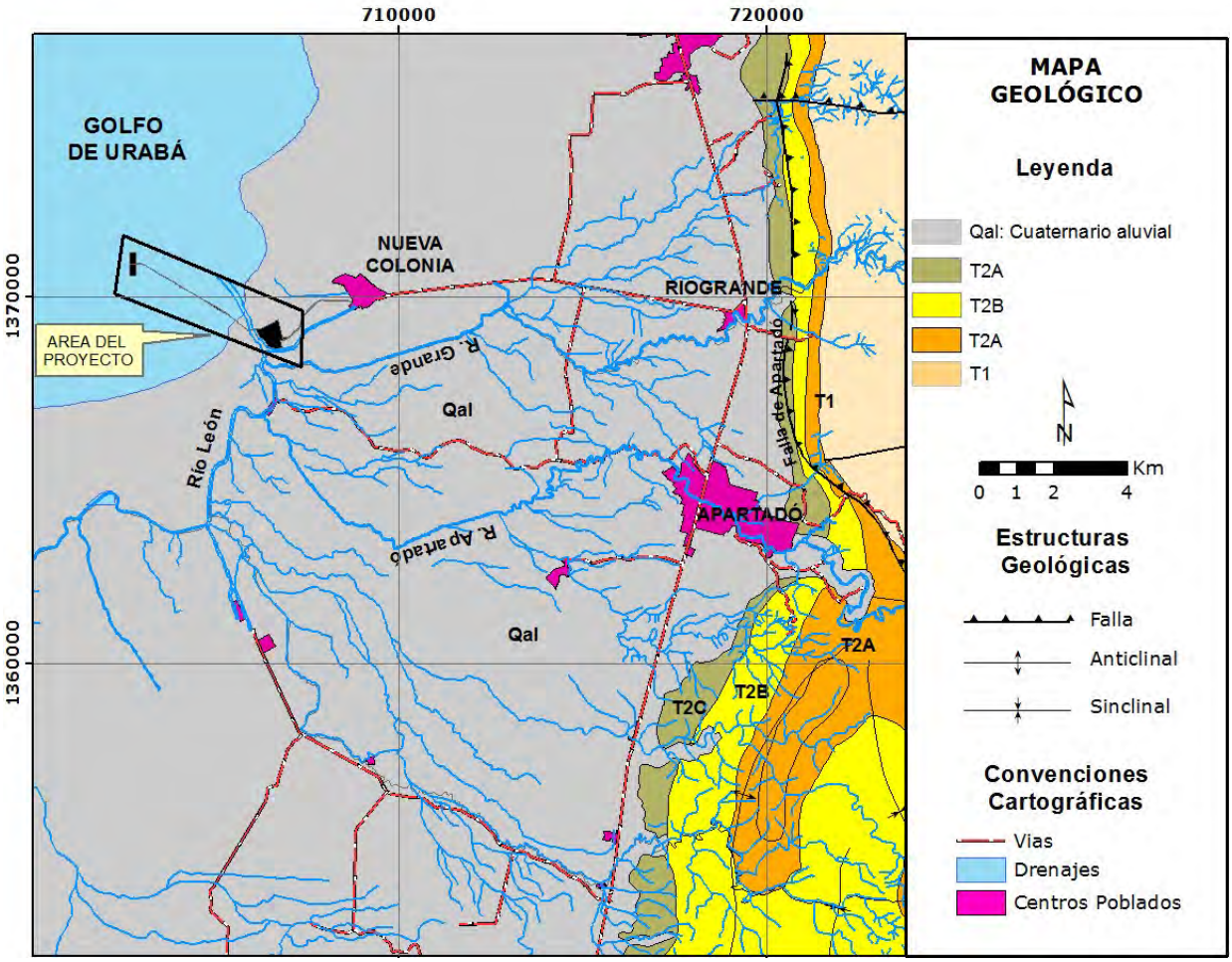

Figure No. 5.2 Generalized geological map of the project area.
Source: Modified of Colombian Geological Service Before known as INGEOMINAS 1995[14].

According to the definition of the International Strategy for Disaster Reduction - ISDR, geological threats are

> Processes or terrestrial natural phenomena, which may cause loss of life or material damage, interruption of social and economic activity or environmental degradation. The geological threat includes internal onshore (endogenous) or tectonic origin processes, such as earthquakes, tsunamis, geological fault activity, volcanic activity and emissions; as well as external (exogenous) processes such as mass movements: landslides, rock falls, avalanches, surface collapses, liquefaction, expansive soils,

[14] COLOMBIAN GEOLOGICAL SERVICE, 1995. Op Cit.

offshore landslides and subsidence. Geological threats can be simple, sequential or combined in their origin and effects[15].

To achieve project safety, it is necessary to identify the geological threats that could occur in the project area, and formulate strategies and measures to address them, either through prevention work, mitigation of their impact or actions to reverse the effects.

According to the geological framework of the area where the project is located, flood threats, coastal erosion, lateral scour, sludge diapirism and earthquakes were identified (see Figure No. 5.3 and Photo No. 5.1)

- Threat by flood

The area where the port facilities will be established is bounded by the León River, it is topographically very low, badly drained and also affected by the daily fluctuations of the tides, a flood could occur in a hypothetical scenario where the León River flood occurs during a high tide. This threat is considered average, since the site where the facilities will be built is separated from the León River by the presence of a high dam that protects it from possible flooding. In the adjacent areas to the coast as well as the natural and artificial drainages a high flood threat was assigned.

- Threat by breaking the left bank of the river

Dredging operations in addition to maintaining navigation, also have the sediment load that reaches the Canal at sea, in the event that such operations are suspended, it is likely that the mouth of the Canal forms a bar of sediment that interrupts its communication with the sea, in this situation the river an opening would probably be made on the southern side which is the most fragile area (see Figure No. 5.3), and in 2006 the Leon River naturally formed a small Canal on the left bank that serves as a spillway (see Figure No. 5.3 and Photo No. 5.1), this canal is still open and would be contributing to the sedimentary processes that occur on the southern side of the coastline, the threat is considered average, since the project could not possibly be affected if the river formed a canal along its left bank through which almost all of its flow flowed, there are two reasons here considered: 1. conditions would be expected to return to those that existed before the deviation of the mouth of the river, where the sediments would be transported by the coastal drift in the NNE-SSO and 2. For

[15] ESTRATEGIA INTERNACIONAL PARA LA REDUCCIÓN DE DESASTRES- EIRD. [En Línea] <http://www.eird.org/esp/terminologia-esp.htm> [Consultado 19, julio, 2015].

the distance of the area of berthing of the ships located 3 kilometers from the coast.

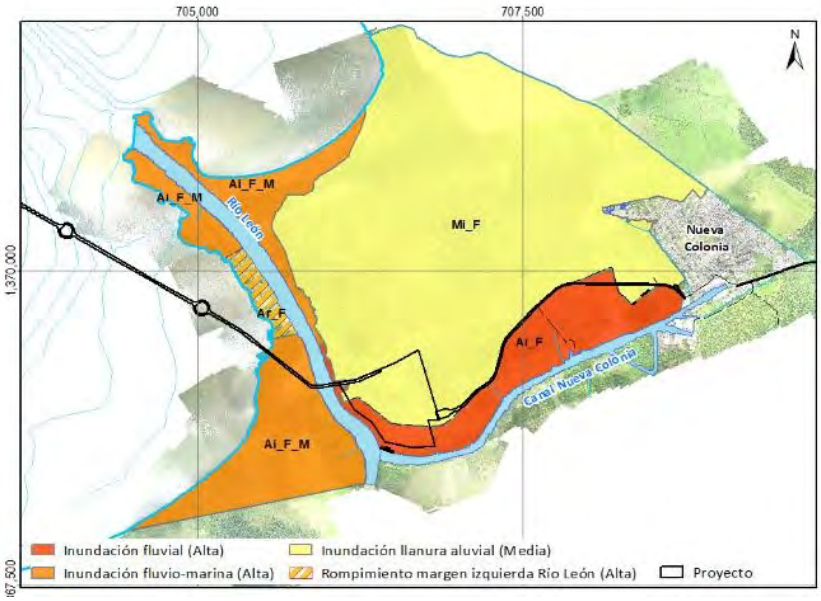

Figure No. 5.3 Identified geo-threats in the project area
Source: Aqua & Terra consultores Asociados S.A.S., 2015

Photo No. 5.1 Natural mouth of the Canal on the left bank of León River
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- Threat by lateral scour

It is a repetitive process where the river tries to expand its waterways and the energy is used in processes of lateral erosion, achieving divagation, and meander development. On the right bank of the Leon River in the section immediately below the mouth of the Nueva Colonia canal (see Figure No. 5.3), a lateral scouring process is currently occurring that is affecting the lot where it is located. they will establish the port facilities. This threat is considered to be high, since it is active and occurs in the area of direct influence of the project.

- Threat by mud diapirism.

The phenomenon of mud diapirism is quite common in the area of the Sinú and San Jacinto belts. In this area, diapirism appears as the most important deforming factor. Much of the area is covered by mud spills from current volcanoes and pre-existing volcanoes, already eroded or asleep. The project area is located to the west of said belts (Figure No. 5.1) so there is very low probability of the occurrence of a mud diapir in the project area

- Seismic threat.

In general terms, seismic hazard is understood as the probability that an earthquake of a certain magnitude will occur in an area in a future period, local conditions determine the possibility of surface breakage due to faults, soil liquefaction and landslides. Because the main causes of earthquakes are faults, which are structures of hundreds of kilometers, these can affect large regions.

To this effect, in the section "Structural features", it was indicated that Apartadó Fault (Uramita Fault) is approximately 13 km east of the project. The effective acceleration peak (Aa) corresponds, to the horizontal accelerations of the design earthquake contemplated in the Colombian Standards of Design and Construction Earthquake Resistant (NSR-10), these accelerations have a probability of being exceeded by 10% in a lapse of 50 years. The value Aa is a parameter used to define the seismic design loads required by the regulations of Resist Earthquake Constructions. In Figure No. 5.4 it can be noticed that the influence area is in a high threat field due to earthquakes.

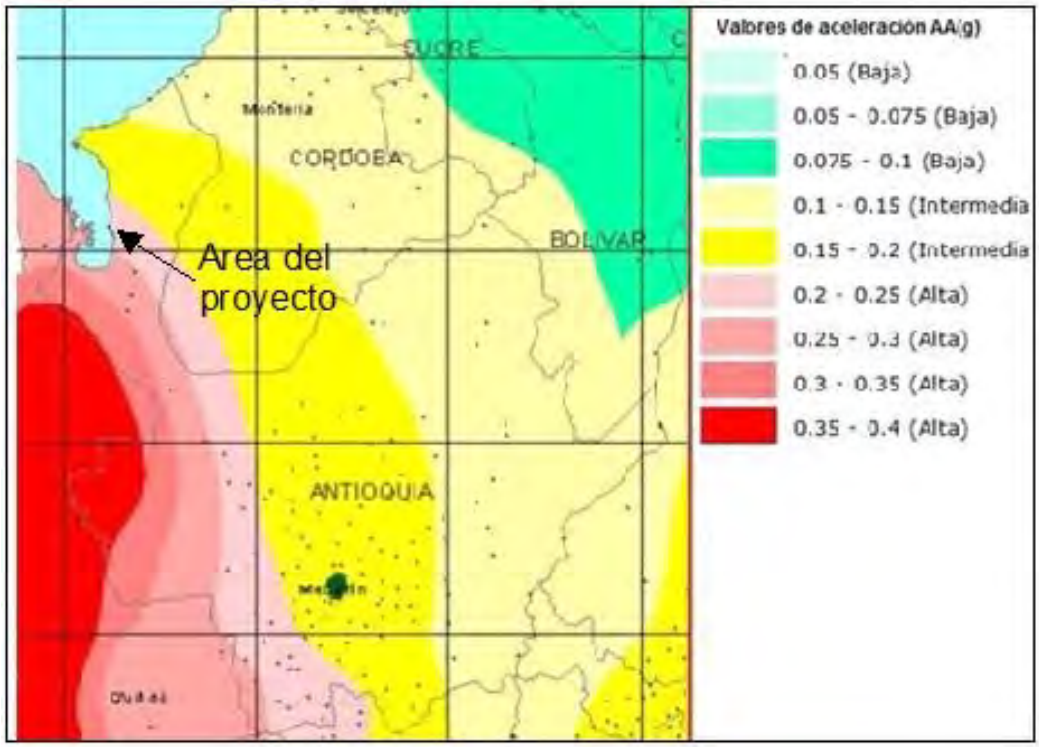

Figure No. 5.4 Map fragment of seismic threat in Colombia.
Source: TECTOCLUB2011[16] .

- *Local Geology*

The local Geology is composed of uninsolidated Quaternary deposits of alluvial or colluvial origin, arranged in the flood plains of the León River and its tributaries that originate on the western slopes of the Abibe Mountain Range

- **Alluvial deposits (Qal)**

The **alluvial deposits (Qal)** are forming alluvial terraces, bars, alluvium, beaches or floodplains, are constituted by sediments of medium to fine textures such as silts, clays, sands, on the shore of the Leon River you can see decomposing organic matter

- **- Recent fluvial-marine deposits (Qfm) and recent marine deposit (Qm)**

Specifically, in the direct influence area of the project, there are **recent fluvial-marine deposits (Qfm)** and recent marine deposits (Qm) that have been made up of mixed

[16] TECTOCLUB2011. [EN LÍNEA] <https://tectoclub2011.wikispaces.com/Tectonica+de+Placas+Aplicada+a+Colombia> [Consultado julio, 18, 2015]

fluvial and marine contributions, composed of silt, clays, fine sands and organic sludge.

In Figure No. 5.5, the distribution of the lithological units in the area of direct influence of the project can be appreciated.

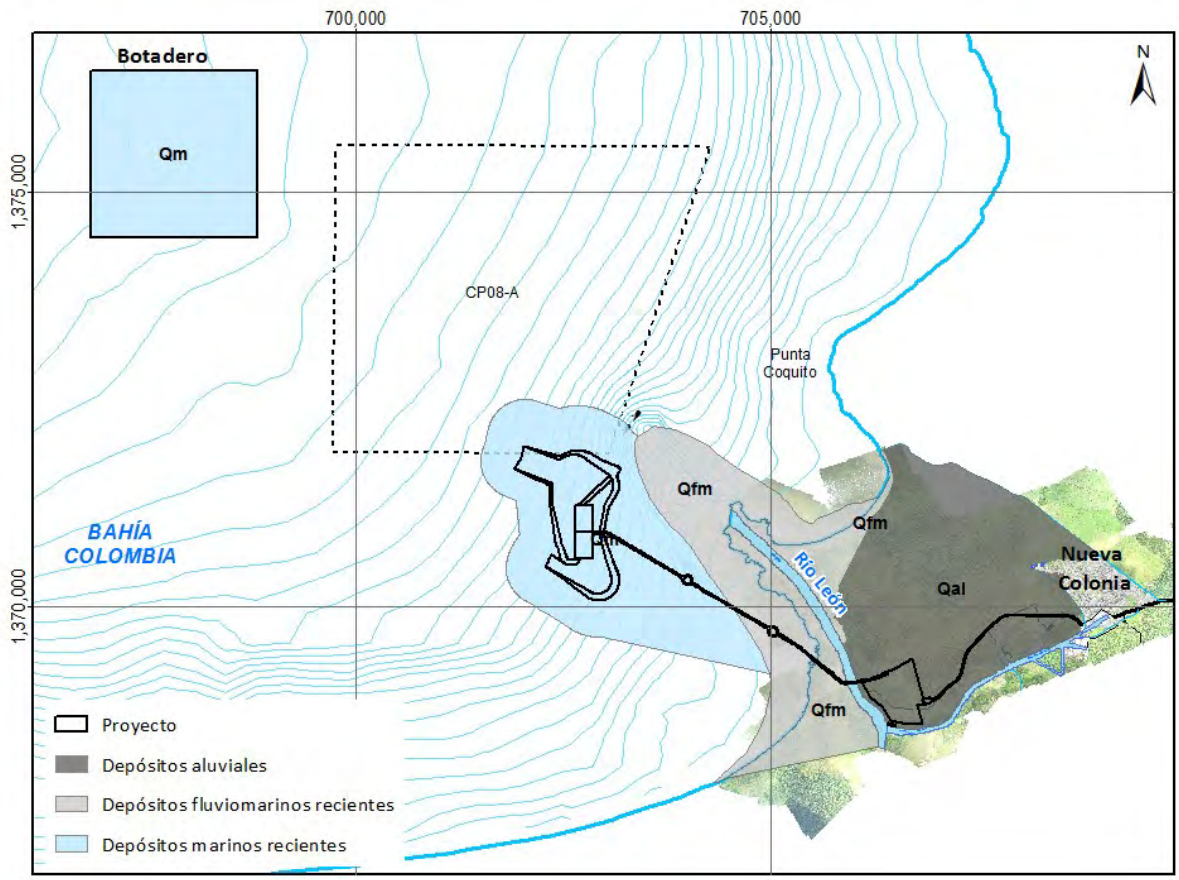

Figure No. 5.5 Local geology
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

5.1.2 Geomorphology

The zone of direct influence of the project is framed in the floodplains of the León River, the surface has a flat topography, whose local relief does not exceed one meter, are the result of the accumulation of sediments of recent age that have been transported by the drainages that run along the western flank of the Abibe Mountain Range

- *Geomorphological units*

The morph dynamic processes that occur in the area have shaped the different forms of relief. Within these processes are the formation of the Abibe Mountain Range, the deposition of sediments in offshore and onshore environments and the modeling effect of the rivers.

In the project area there is currently a strong interaction between anthropogenic activity and oceanic and fluvial processes, the combination of these processes added to the climate, has resulted in the current geomorphology of the area (see Figure No. 5.5 and the map). MOD_LA_PTO_ANT_07_Geomorphology).

- Alluvial plain of the León River

In the data model of the ANLA, it corresponds to the active floodplain of the meandering River, it is a plain built by the León River that passes through the study area and presents a meandriform Behavior. The port facilities will be built on this geomorphological unit, the alluvial plain is characterized by presenting a flat, slightly permeable relief that remains waterlogged most of the year. The alluvial plain is formed by fluvial sediments of recent age composed of silts and clays that have a high content of organic matter.

The morph dynamic processes that act on the alluvial plain unit have allowed the development of the following geoforms:

Natural Dams. A natural dam is a narrow and elongated sedimentary deposit that is located on the margins of the rivers, resulting from the deposit of the materials dragged by the rivers at the edge of it during the floods, this progressively causing the elevation of the riverbank, Leon river dams are made up of very fine sand, silt and clay, topographically correspond to the highest areas within the alluvial plain of the river. In the project area, the natural dams have an approximate width of 50 m.

In the León River dredging operations have been carried out periodically for approximately 25 years, the materials extracted from the riverbed have been deposited in the areas surrounding the river, forming artificial and natural mixed dams (see Photo No. 5.2), this is the case of the property where the port facilities will be built, where materials obtained by the dredging activities have been deposited, improving their drainage condition a little, which has allowed the development of the livestock activity.

Photo No. 5.2 Dam on the right bank of the León River
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Meander bars. They are elongated and curved geoforms that form on the inner edge of the meanders, through the successive deposition of relatively thick alluviums (sands and silts). Generally, the meander bars are stable staying throughout the year regardless of whether the season is dry or rainy

Longitudinal bars. In the León River during the dry season the excess sedimentation along its channel is manifested in the formation of sediment bars that are arranged parallel to the river banks (see Photo No. 5.3), in the mouth nearby area at low tide, the longitudinal bars can be seen and usually disappear with the arrival of the rainy season when the river levels increase.

Photo No. 5.3 Longitudinal bar of the León River, partially covered by water.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- León River Delta

The processes that occur at the mouth of the León River are very complex since in this area oceanic, fluvial, wind and anthropic agents are interacting, as a result of interaction added to the high amount of sediment load that the León river delivers to the sea at its mouth, an intense sedimentary process is generated that has resulted in the formation of a delta, which gradually increases its dimensions and moves towards the sea, the dredging activities that are carried out periodically in the area has allowed to maintain navigation through this body of water, but it has not been possible to stop its advance towards the sea.

With the current sedimentary dynamics at the mouth of the León River, the landscape, the Onshore environment and the bathymetric configuration of the sea have been affected, causing difficulties in navigation operations.

Morphology of the León River Delta

Deltaic plain emerged. It represents the emerged part of the delta (see Photo No. 5.4), is cut by a Canal that connects the León river with the sea, is made up of materials of offshore - alluvial origin, these are poorly drained marshy areas**.**

Photo No. 5.4 Deltaic plain, right bank from the Canal to the sea
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Canal to the sea. It is a navigable waterway that connects the León River with the sea (see Photo No. 5.5), It was built artificially in 1989. The materials transported by this body of water are deposited in the most proximal part of the delta front.

Photo No. 5.5 Canal aspect of the sea, near the mouth of the León river.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Delta front. It corresponds to the shallow marine area that borders the deltaic plain, where a large part of the sediments carried by the canal to the sea are accumulated

Underwater delta plain. The sediments transported by the onshore drift as well as the materials from the dredging activity in the Canal to the sea, are deposited on the

areas located on both banks of this water body, where they have gradually formed extensive shallow subaquatic areas with lower depths to one meter.

Sandy beaches. This geoform appears in the southwest border in which the delta marks limit with the onshore complex, it is a very stable area where the processes seem to have reached a dynamic equilibrium, it is about narrow beaches from 1 to 3m wide formed by fine sands and silts (see Photo No. 5.6). The beaches change from one climate to another, so in the rainy season when the wave energy is low in the gulf, the beach face is wider and retains more sand than during the dry season[17].

Photo No. 5.6 Narrow sandy beach.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

The following is a brief explanation of the most common types of deltas and their origins to understand the León River Delta.

[17] VELÁSQUEZ, C. y J. RAVE. Dinámica costera y geomorfológica en el Golfo de Urabá Antioqueño. Sector Boca Tarena – Espiga de Turbo. Trabajo de grado, Universidad Nacional, Facultad de Minas, Medellín. 1996, 136 p.

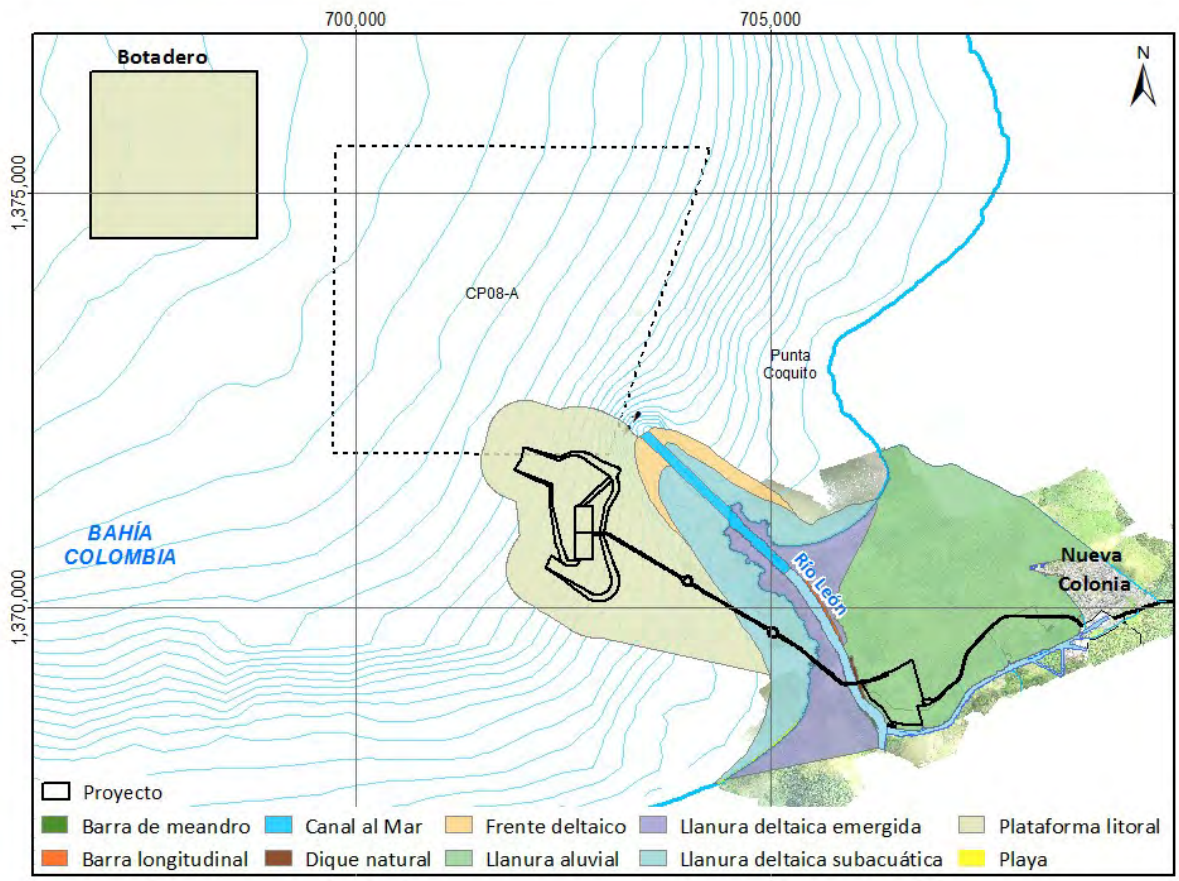

Figure No. 5.6 Geomorphological units present in the project area.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Types of deltas [18][19][20]

When the rivers flow into the sea, the river currents decelerate sharply, due to the dispersion of the flow in a water volume of considerably greater proportions. This process causes sedimentation of most of the sediments carried by the river, this process of sedimentation builds the structure of the delta.

The morphology of the coasts, and particularly of the deltas, varies according to the relative importance of three factors:

[18][On Line] <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/ deltas/page6.html>. [Last checked July 11,2015].
[19] COLEMAN, J.M. Deltas, Processes of Deposition and Models for Exploration. International Human Resources Development Corporation, Boston, 1982 p. 124.
[20] LONGHITANO, S., COLELLA, A. Geomorphology, sedimentology and recent evolution of the anthropogenically modified Simeto River delta system. *Sedimentary Geology* ***194*** *(2007) pp.195–221.*

*The importance of contributions and fluvial processes.

*The energy of the waves.

*The one of the tides.

Each type of delta is characterized by a different morphology as well as by different geometries and properties of the sandy bodies. Actually, in most deltas, the facies reveal combined influences of the three factors.

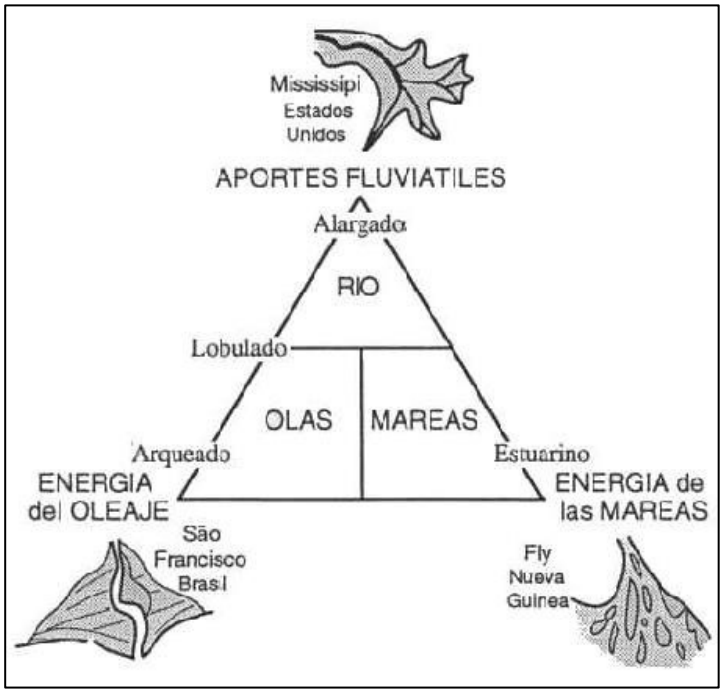

Figure No. 5.7 Deltas classification according to the dominant process.
Source: On Line <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/ deltas/page6.html>. [Last checked on o, 11, 2015].

Deltas with fluvial predominance

These deltas were the first studied, thanks to the numerous works started in the 1950s on the Mississippi delta. For a long time, said delta was considered as the typical example of delta, and all the others were compared with this one.

Morphology. The deltas with fluvial prevalence are generally lobed (more common) when they accumulate in shallow onshore areas, or elongated when they are built in deeper waters, for example on the edge of the onshore platform. Most of the old

deltas seem to be rather lobed. Despite their morphological differences, these deltas have common sedimentological characteristics.

Distributary canals. They form a branched network from the main river, they are also narrow and of weak Sinuosity, which contrasts with the main river, often more meandering. When the river changes course and leaves a distributary canal, the latter is filled by fluvial sands, which form a narrow and elongated body with thicknesses that reach 15-20 m and a maximum width of 1 to 2 km. A characteristic sequence of canal is that this has an erosive base, a filling of clean sands with oblique stratification and finishes by finer deposits, such as clays and fine sands with ripples of steam and traces of roots.

Inter-canal areas The distributary channels are bordered by hills, constructed by the deposit of silty and sandy sediments in suspension, during flood overflows. The Inter-canal areas are topographically lower and form swamps or bays. During the floods, they receive clay sediments that alternate with sandy beds. These come from the spreading of coarse material carried by the water that leaves the canal of the river during floods, through gaps. Said deposits of water release can form sandy fans of several tens, or even hundreds of km^2 of surface

Mouth bars. They are deposited in the mouths of the distributary canals; they are sandy bodies in the shape of a fan that program over the clays of the prodelta. The resulting sequence is grainy and gradual. The sands of these bars are generally dirtier and thinner than those of the canals, but they have a wider geographic area (several Km.) With a power from 2 to 10-15 m

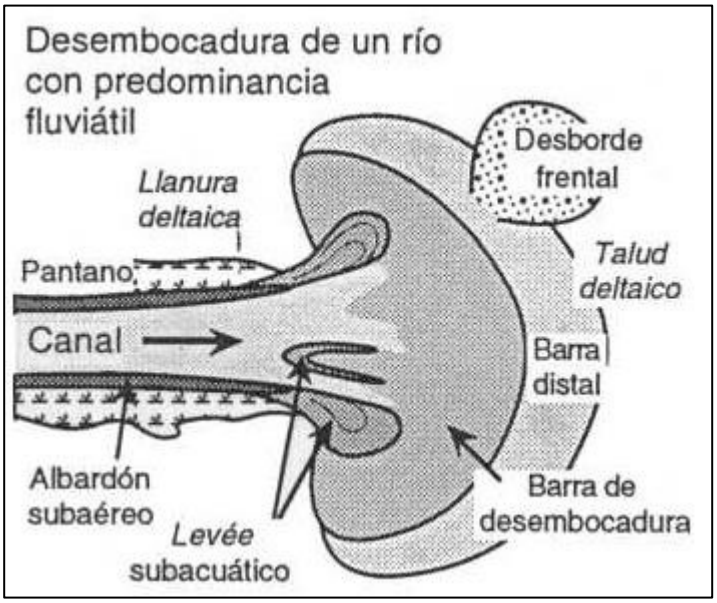

Figure No. 5.8 Mouth of a river with fluvial predominance.
Source: On Line] <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/ deltas/page6.html>. [Last checked July 11, 2015].

Deltas with predominance of tides

Morphology. It is characterized by estuarine distribution canals: widening mouth (the fluvial mouths are narrow), bordered by tidal clay plains (tidal fiat, mud fiat), and upstream meandering channels

Distributed channels. They generally lack marginal hills, in the channel sands accumulate, often in the form of meander bars. These deposits are more extensive than those of the river deltas

Interlacial areas of deltaic plain. They are constituted by tidal silty plains and swamps. In areas with semi-arid climate, evaporites are found.

Mouths. The sand is deposited in the form of tidal bars, whose shape depends on the action of the ebb and flow streams, they are sometimes elongated, sometimes lobed. They contain stream figures with opposite senses translating the opposite directions of the ebb and flow. They program on the marine clays of the prodelta, forming gradational-based gradation sequences.

The characteristics of these deltas are induced by the tides, which generate the reworking of the sediments by alternative and cyclic streams. This continuous action contrasts with the more sudden and catastrophic events of the rain floods, and it is

reflected by the presence of repeated layers of tidal cycles, of clayey laminations in the sands, and by sigmoidal stratifications.

Figure 5.1 Mouth of a river with waves predominance
Source: On Line] <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/ deltas/page6.html>. [Last Checked July, 11, 2015].

Deltas with waves predominance

When the waves arrive obliquely with respect to the coastline, refractive, diffraction and reflection effects produce a parallel stream to the coastline between the wave zone and the shore known as onshore drift (Figure No. 5.9). The speed of the drift is minimal outside the area of the wave, which clearly shows that it is induced by the waves and cannot be attributed to ocean streams or tidal streams. These streams are able to transport laterally, sometimes over long distances, sediments carried to the coast by rivers.

The waves are felt most of all in the outer part of the delta plain and the delta front. In these areas, the turbulence of the breaker and the seesaw of the waves prevent the deposition of thin sediments, which are dispersed towards the sea, and causes the continuous reworking of the rain sands and their lateral transport, if there is an onshore drift

Morphology. It is arched, the onshore drift transports most of the fluvial sand out of the mouths, forming coastal cords and beaches. If the action of the waves is weaker, the beach cords are not attached to the coast, and form coastal cords that limit lagoons.

Distributary canals. If the action of the waves is very strong, the delta will only have few major distributaries, since the littoral cords cover the secondary canals.

Intercanal areas of deltaic plain. They are almost entirely constituted by beach sands, cut by the distributary channels. If the action of the waves is smaller, the deltaic plain is made up of lagoon or swamp shales deposited behind the sandy cords.

Mouth bars. They are slightly developed, since the sand is reworked and transported. The main characteristics of the deltas dominated by the waves are the presence of beach and ante-beach sands, organized in prograding cords. These deposits can be very extensive and are parallel to the coast, while in the other deltas, the sandy bodies have major axes perpendicular to the coast (tidal bars, fluvial channels). The canal mouths are more scarce, but they can cut the beach sequences. Sedimentary figures attest to the action of waves and storms oblique laminations in mamelons (HCS), gradational-based classified layers, symmetrical ripples of waves, etc.

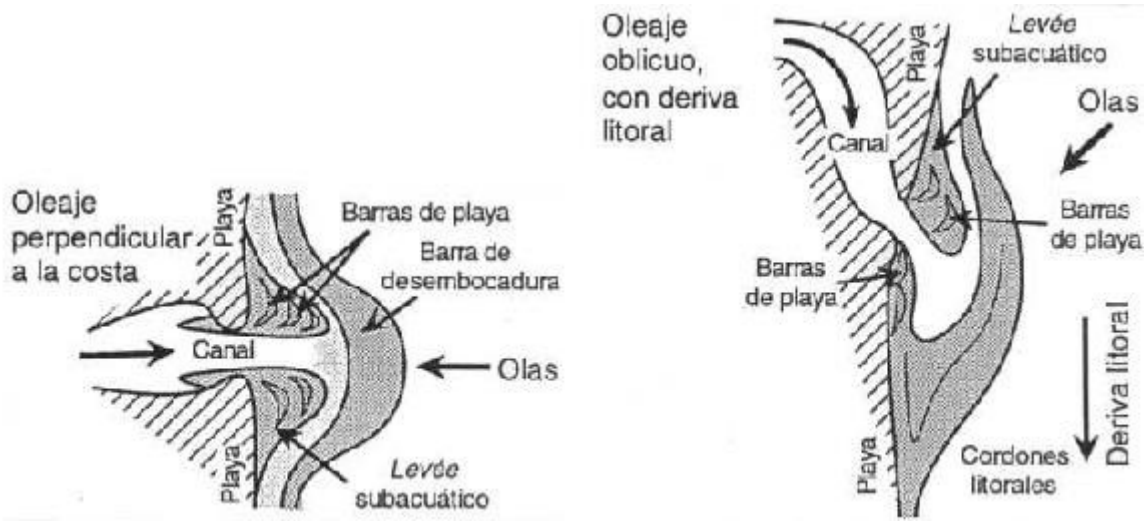

Figure No. 5.9 Mouth of a river dominated by waves, to the left the waves arrive perpendicular to the coast, on the right the waves arrive obliquely inducing an onshore drift.

Source: On Line] <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/ deltas/page6.html>. [Last checked July, 11, 2015].[21].

- Littoral platform

The submarine relief of the Caribbean is defined by the characterization and identification of the geoforms according to the toponymy consigned in the bathymetric charts of the DIMAR. The continental shelf is in the area adjacent to the land area of

[21] [On Line] <http://fluidos.eia.edu.co/hidraulica/articuloses/flujoencanales/deltas/page6.html> [Last Checked July 11, 2015]

the continent, which extends from the low-water line to a depth in which there is usually a marked increase of the slopes towards the ocean depths.

The study area of the project is located on the o shelf of the Colombian Caribbean, which has a length of 1,700 km cut by a series of canyons that extend almost perpendicular to the coastline and bear some relation to the main onshore faults[22].

The coastal platform of the study area is strongly influenced by the discharges of the Atrato River, which includes the inner part of the Gulf of Urabá where the project is located, which is characterized as a sandy platform and sandy mud[23].

- *Dynamics of processes*

In order to know the intensity of the dynamics of the morph sedimentary processes (erosive and sedimentary) that act on the different geomorphological units, a multitemporal analysis was carried out with the help of aerial photos of the IGAC between the years 1983 and 1989, which were georeferenced, aerial photos of the project area taken in 2014, Google Earth images between 2010 and 2014, surveys of the coastline from 1994, 2004 and 2007. In Figure No. 5.10, it can be seen the geoforms in which the main morph dynamic processes are presented

- Rain Processes

The course of the Leon River waters has remained with very few changes from 1983 to 2015, despite the interventions it has been subjected to and the increase in the sediment load, however on the right margin in the section that is located immediately after downstream from the mouth of Nueva Colonia canal, there is currently a scouring process that is affecting the property where the port facilities will be established, this scouring process has caused a widening of the hydraulic section that passed 95 m in 1983 to 156 m today (Figure No. 5.10)

[22] HYDROLOGY, METEOROLOGY AND ENVIRONMENTAL STUDIES NSTITUTE - IDEAM, AGUSTÍN CODAZZI GEOGRAPHICAL INSTITUTE- IGAC; INSTITUTE OF RESEARCH OF BIOLOGICAL RESOURCES ALEXANDER VON HUMBOLDT - IavH; INSTITUTE OF MARINE AND COASTAL INVESTIGATIONS JOSÉ BENITO VIVES DE ANDREIS - INVEMAR; AMAZON INSTITUTE FOR SCIENTIFIC RESEARCH SINCHI -I.SINCHI; ENVIRONMENTAL RESEARCH OF THE PACIFIC INSTITUTE JHON VON NEUMAN - IIAP. Continental, coastal and marine ecosystems of Colombia. National Printing of Colombia. Bogotá D.C., 2007. 276p + 37 cartographic sheets. ISBN 978-958-8323-16-9

[22] Ibid.

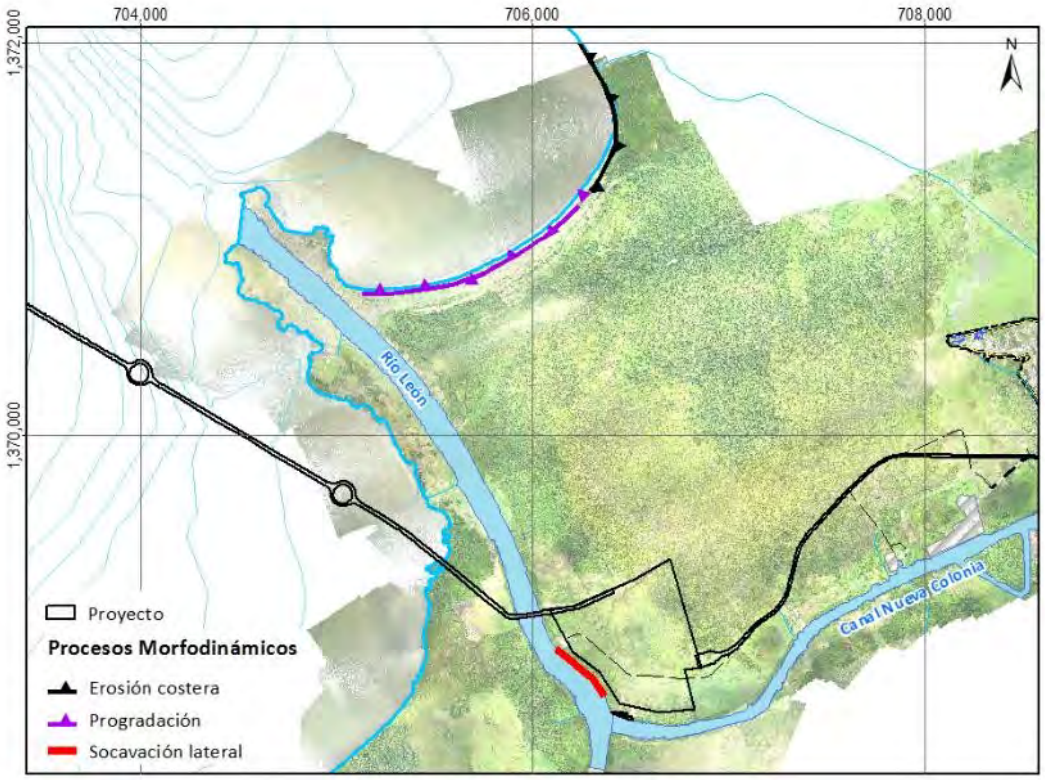

Figure No. 5.10 Morph dynamic processes that act on the geoforms in the study area.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

This change in the dimensions of the canal affects the processes in this section of the river, causing a strong sedimentary process on the left bank, where a sediment bar has been formed. A hydraulically efficient section maintains a balance between the flow and the amount of sediment that the stream is capable of transporting, this type of section is achieved when the dimensions of the section reach the minimum width - depth ratio, since the ratio between the dimensions' depth and width of the section against its transport capacity are inversely proportional, as the section becomes wider or deeper its transport capacity will decrease.

- Changes in the delta morphology

According to the information provided by the Association of Banana Growers of Colombia - AUGURA, in 1988 the mouth of the León River, which had a predominant direction to the South and was diverted towards a Northwest direction to improve the navigability conditions of the banana bongos, in Photo No. 5.7 the appearance of the mouth of the river León for the year 1983 can be seen, the banana bongo seen in the Photo would show the direction of the river to reach the sea, while the coastline

indicates that the sediment load from the river was distributed in elongated bars to the south and parallel to the coast, taking into account this Behavior and according to the previously explained in the separate "Types of deltas", it can be affirmed that before the deviation of the mouth of the León river in 1988, the delta presented a morphology of a delta that is controlled by the waves, which distributed its load of thirst Implants in elongated bars to the south and parallel to the coast, a relevant aspect in the stream morphology of the delta is that it is a rain influenced delta, which distributes its sediment load preferentially in a perpendicular direction to the coast (see Photo No 5.8), the anthropic intervention that has been carried out with the dredging operations has forced it to remain with a single canal. Additionally, note the "nozzle" effect of the sediment plume in front of the channel mouth

The existence of a single channel is explained because it is not the case of one of a free delta in which the sedimentary processes occur naturally, it is a delta subjected to dredging to maintain an efficient hydraulic section for navigation and efficiency it would not be achieved if the flow were dispersed by several channels, however the fact that there are only one channel potentates the concentration of sediments in its mouth, allowing accretion processes to be generated towards the sea.

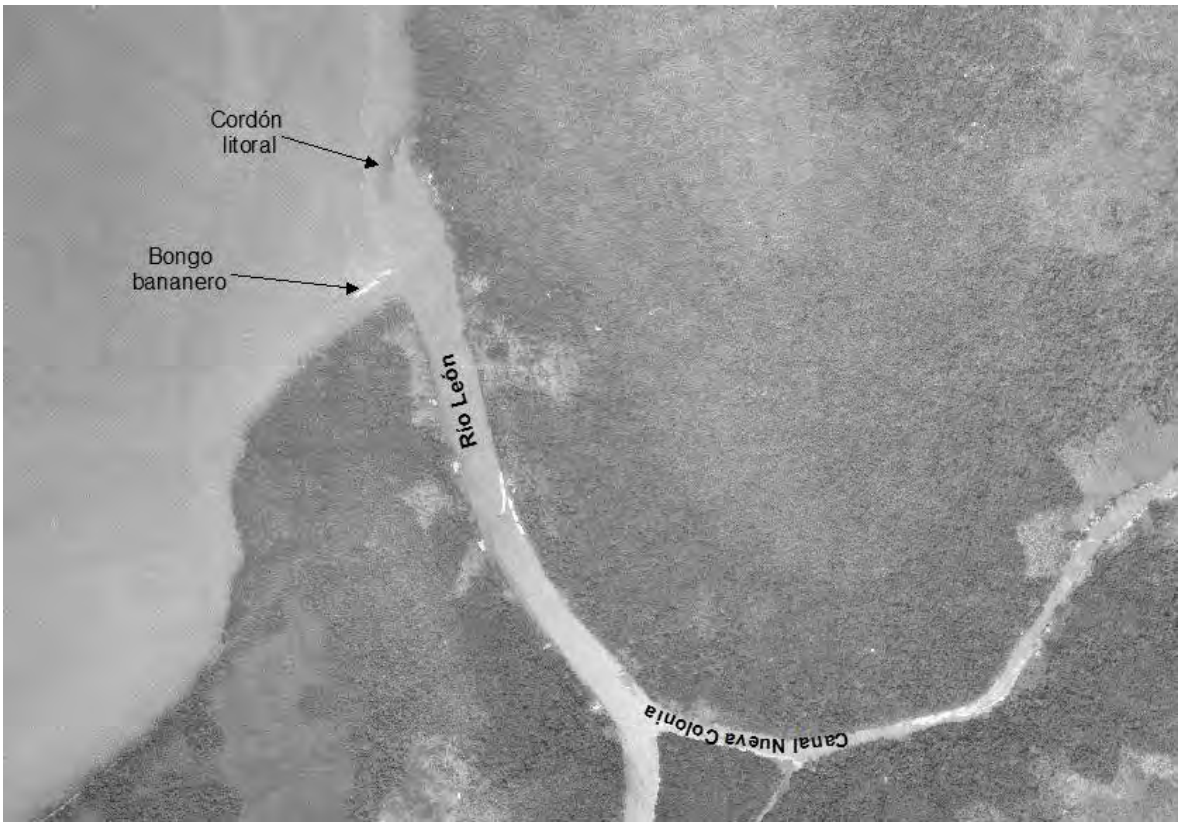

Photo No. 5.7 Mouth of the Leon River appearance in 1983.
Source: Air Photo IGAC 1983

Photo No. 5.8 León River Delta. Sediment deposits are distributed perpendicular to the coast.
Source: Google Earth Image November 1-2014.

- *Evolution of the León River Delta*

The main changes that this body of sediment has experienced are the following:

- Distribution of the delta towards the sea

After the deviation of the mouth of the river, the sedimentary processes that were initially concentrated in the mouth of the river have been gradually transferred year after year towards the sea direction, during a period of 25 years counted from 1989 to 2015, the body of sediment has moved approximately 2250 m, this represents an annual rate of 90.1m. In the area located in front of the canal mouth is where the delta records its largest displacements to the sea, during the period 2013 - 2007, this displacement was 509 m, which is the equivalent to 84 m annually (see Figure No. 5.12), which gives it an elongated shape. The explanation of why the delta moves perpendicular to the coast in the direction of the sea, is probably due to the canal channeling sediments towards its mouth acting as a nozzle (see Figure No. 5.11),

once the sediments reach the mouth these continue their way through the sea, where they begin to settle.

- Conformation of shallow areas

The sediments transported by the onshore drift as well as the materials from the dredging activity in the Canal to the sea, are deposited on the areas located on both banks of this body of water, where they have gradually formed extensive shallow subaquatic areas with lower depths. to one meter (underwater deltaic plain) and emerged marshy areas along the Canal to the sea, which have been colonized by vegetation, in Figure No. 5.11 it can be observed that the limits of these areas were established by the bathymetries carried out in the years 2007 and 2013. The expansion rate of these shallow laterals is less than the displacement that occurs in the frontal part of the delta, hence this sediment body has an elongated shape.

- Sedimentary processes

Before the diversion of the river mouth, sedimentary processes were of lesser magnitude, to this effect in the study carried out for UNIBAN by SADEC [24], it is affirmed that the León river does not form a delta and that the watercourses that flow to the south of the Colombia Bay do not form deltas but their sediments are scattered by the sea, likewise affirms in said study that the morphology at the mouth of the León river remained almost unchanged during the period between 1946 and 1989.

With the deviation of the river mouth, the currents of the river that have a SE-NO direction meet the onshore drift currents that have a predominant direction NNE-SSO, as a consequence there is a partial speed cancellation of the involved streams in this encounter, in such a way that the resulting current presents a speed that would not be completely able to transport the combined sediment load of the river and the drift, a situation that would cause the deposition of part of the sediment load, as there is only one canal it potentiates the concentration of sediment in your mouth, allowing processes of accretion to the sea to be generated.

In addition to the deviation of the mouth, sedimentary processes have been favored by the increase in the sediment load coming from the Leon River basin, previously the water courses that descend from the Abibe mountain range and that flow into the León river, deposited most of the materials they transported in their flood plains. The Leon River, on the other hand, presented a dynamic dominated by the overflows from

[24] AEROFOTOGRAMETRIC SERVICE OF COLOMBIA - SADEC. Geomorphological Study of the Sector that Includes the Final Course of León, Currulao and Turbo rivers, as well as its Outfall in the Gulf of Urabá. 1990.

which the sediments also accumulated in its floodplain. In such a way that an important fraction of the sedimentary load coming from the basin was deposited in the floodplain of the river without reaching the sea. But with the construction of veins on the banks of the rivers and drainage works, it is avoided that these discharge their sediment load on the floodplain, on the other hand the changes in the vegetal cover where the natural forests have been replaced by pastures for livestock and clean crops, which generate erosive processes representing a greater volume of sediments.

According to the above, it is expected that the sedimentary processes along the course of the León River and its delta will continue to occur, since the conditions that gave rise to these processes are still present.

- Coastal erosion processes.

Basically it is throughout the whole delta where sedimentary processes occur, however on the southern side of the Canal to the sea irregularities in the contour of the coastline and the presence of islets that have been colonized by mangroves (see Photo No. 5.9), would be indicating the presence of erosive processes, however when comparing the Google Earth image of 2010 with the aerial photo of the project area, as well as the information obtained from the field, it was determined that currently in the southern sector of the coastline sedimentary processes are presented (see Figure No. 5.11 and map MOD_LA_PTO_ANT_09_Susceptibility).

Photo No. 5.9 Colonized islets with mangrove
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

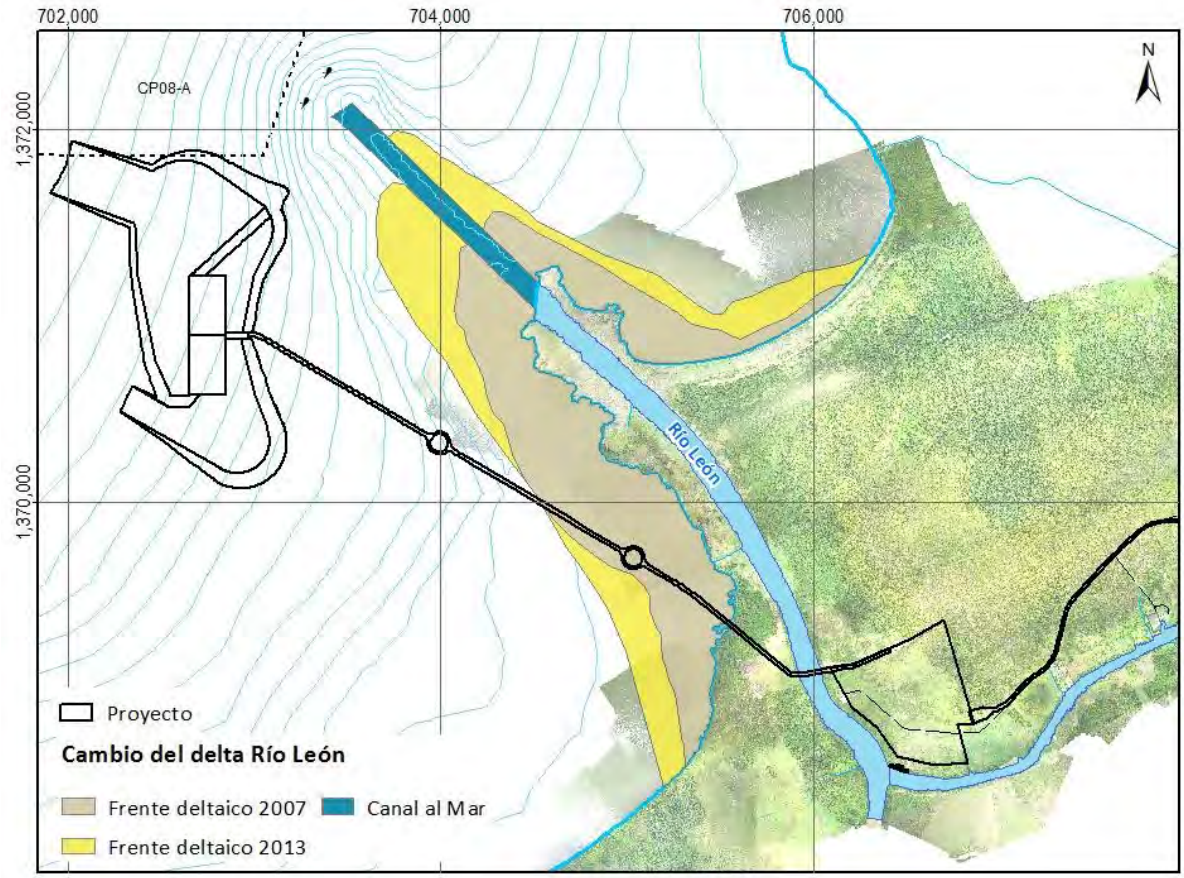

Figure No. 5.11 Delta evolution between 2013-2007 period.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- Accretion processes

The processes that occur in the delta also affect the frontal part of the Leon River floodplain and the coastline; boundary between the right margin of the Canal and the sea has formed a wedge-shaped area (see Figure No. 5.12) whose extension is 56 hectares, its formation can be explained considering the emerging dams that are on both banks of the Canal , which would function in a manner similar to a spur, that is to say retaining part of the sediments transported by the coastal drift, and since the predominant direction along the year of the coastal drift is NE-SO, currently the processes of Accretion continue active.

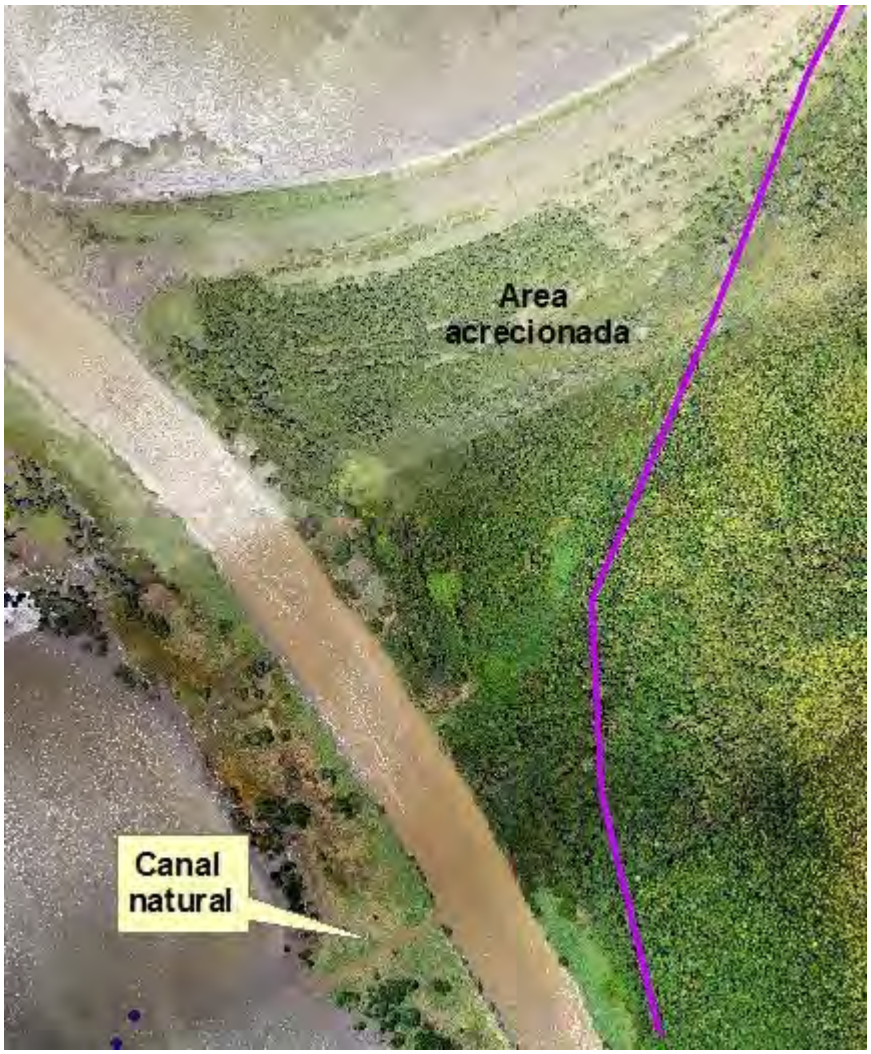

Figure No. 5.12 Wedge sediment between the right bank of the León River and the sea that has been shaped by the "spur" effect of the bar on the right bank of the river.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Morphology and evolution of the coastline*

The shape of the coastline is an indicator of the morph dynamic processes between the sea and the continent, the coast lines located on the North margin of the Canal to the sea, are smooth and continuous, reflecting constant conditions of a process as Over time, according to the available information obtained from the tracings of the coastlines from the year 1983 to the present, it can be seen that this part of the coast has been shaped by a sedimentary process, perhaps augmented or originated by human intervention, to date, as a consequence of this process since 1983 the

coastline has experienced a transgression of approximately 420 m, this is an average annual rate of 13m (see Figure No. 5.13 and the map MOD_LA_PTO_ANT_08_Morphodynamics).

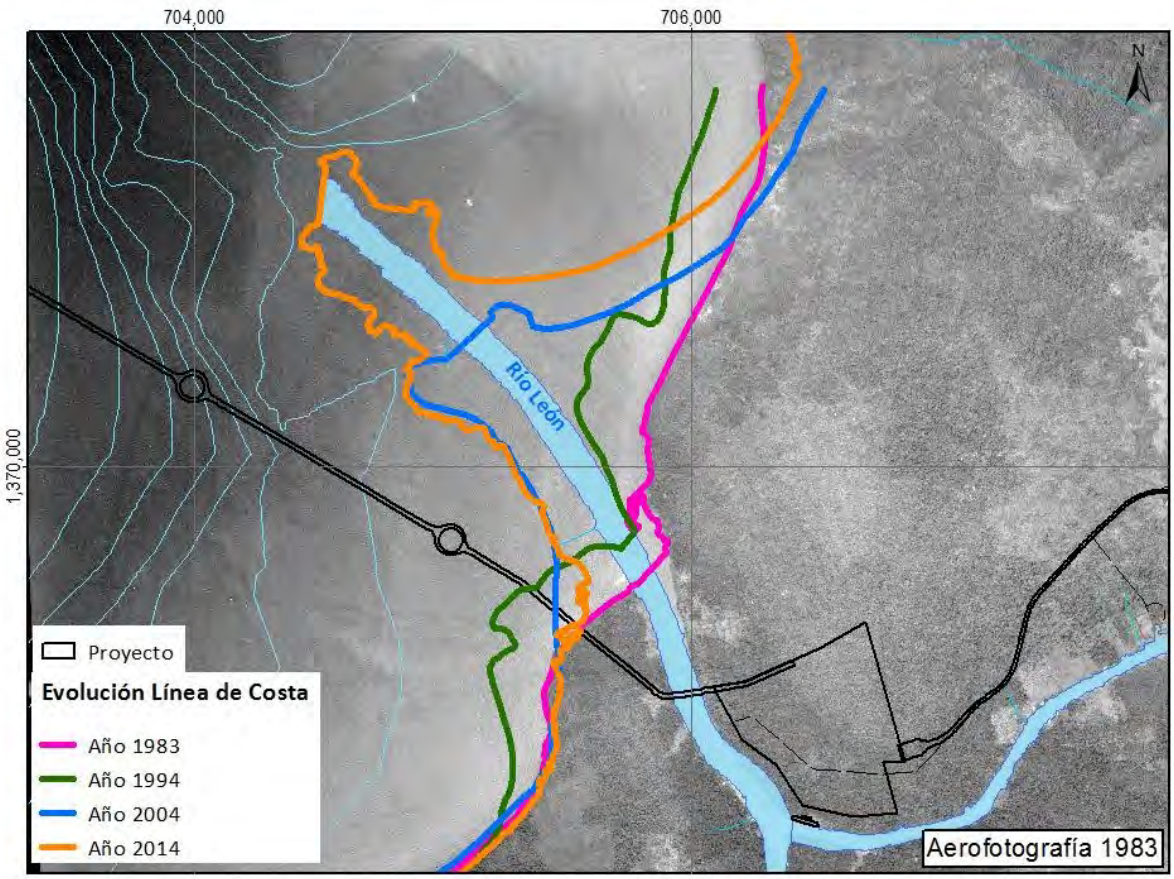

Figure No. 5.13 Offshore movements - Photo 1983
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

On the other hand, the morphology with the irregularities in the contour of the coast line located on the south side of the Canal to the sea with inlets and outlets and the presence of islets that have been colonized by mangroves (see Photo No. 5.7), would indicate the occurrence over time of both sedimentary and erosive processes, the result of these processes show a coastline where transgression or marine erosion have remained in dynamic equilibrium, however at present, according to the information available and comparing the image obtained from the Google Earth server of 2010 with the Aerial Photo of the project area, it can be concluded that a sedimentary process would be present, the possible source of sediments would be the natural canal mentioned above.

Figure No. 5.14 shows the evolution of the coastline since 1983.

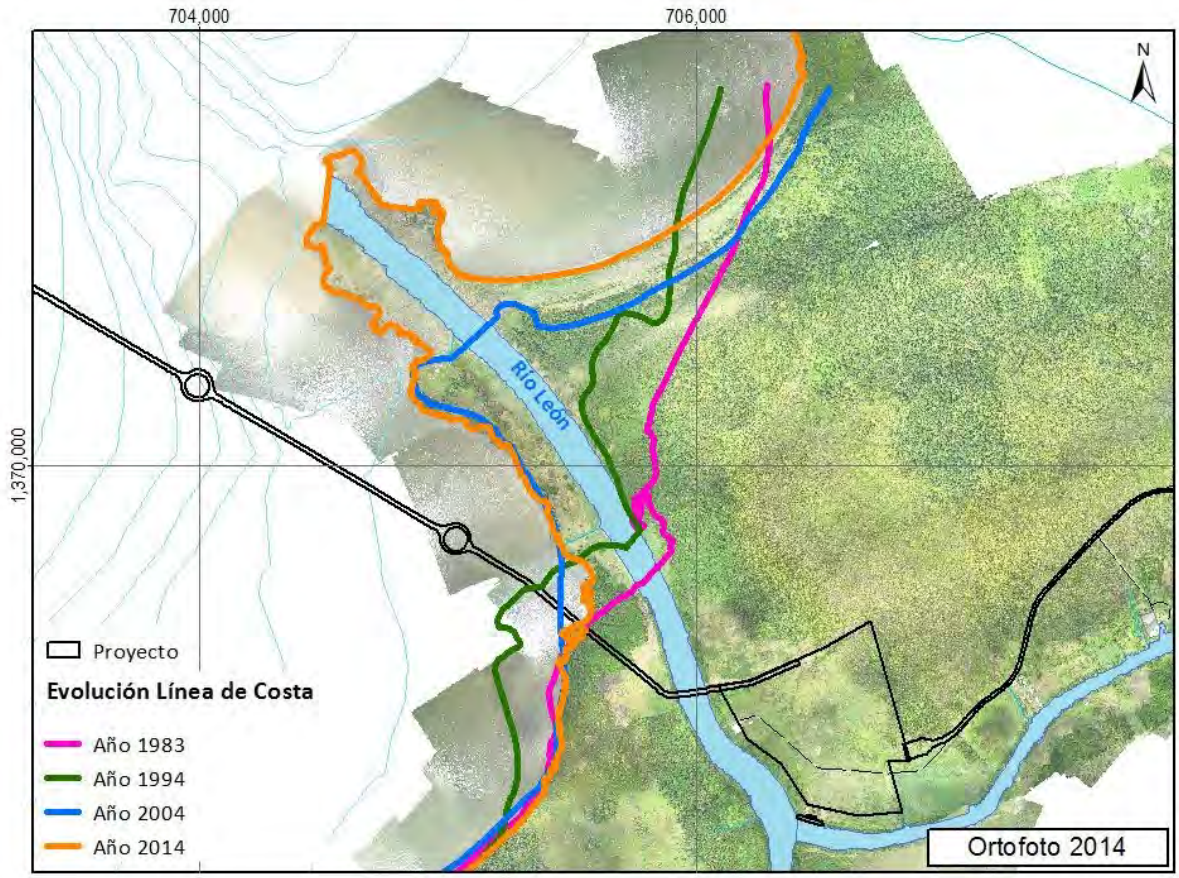

Figure No. 5.14 Offshore movements from 1983.
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Bottom morphology*

- Bottom morphology area of deepening dredging

The morphology of the bottom in the project area is controlled by rain contributions and oceanic dynamics. The seabed is composed of a thick layer of recent muddy sediments resting on sedimentary rocks of the tertiary, the recent sediments come from the rivers that flow into the Gulf of Urabá, the Atrato River is the one with the largest volume of sediments, followed by the León River, while the Suriqui River is considered important due to its proximity to the project area.

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Figure No. 5.15 and Figure No. 5.16 represent the bathymetric conformation of the study area, obtained from the bathymetric survey carried out in May 2014, where the main bathymetric characteristics of the influence area of the project can be observed, the bathymetric levels show a monotonous increase in the SE-NW direction, reaching 12 m depth approximately 3 km away from the current coastline specifically in the area where the dock will be built, while in the perpendicular direction that is SW-NE, the levels are constant, this bottom configuration resembles an inclined plane, with a slope of 0.2 °, equivalent 0.35%. In the Northeast sector in front of the mouth of the Canal to the sea, the isobaths have a convex shape towards the sea indicating the presence of sedimentary processes. Towards the extreme Southeast, the isobaths exhibit a concavity towards the sea (reflecting the erosional conditions of the area indicated above), possibly originated by a deficit of sediments in the area. The bathymetric conformation for distances greater than 3 kilometers from the coast shows quasi-straight isobaths indicating that the morph-sedimentary processes are in dynamic equilibrium. See map MOD_LA_PTO_ANT_10_MDT.

- Bottom morphology area of dumping

The morphology of the seabed in the southern part of the Gulf of Urabá, forms an elongated depression in the Northeast, with depths that reach -28 m in the deepest zone located southeast of Leoncito arm of the Atrato River, said depression is enclosed for all its sides except for its northern side, the isobaths that demarcate this depression are elliptical with their major axes oriented in the NE direction.

The slopes on the eastern side show very smooth and monotonous slopes of 0.21% or 0.12 °, on its southern side the slope is slightly higher with 0.32% or 0.18 °, while on the west side in front of El Leoncito arm opening of the Atrato River, the slopes show their highest slopes reaching 2.4% or 1.4 ° this may be due to a process of accretion of the continent towards the sea as a result of the intense sedimentation that occurs in this sector

The shape of the isobaths does not allow to conclude with certainty about the presence or not of sedimentary or erosive processes, however the elliptical shape of the isobaths with their major axis oriented in the NE direction could be indicating the presence of a structural control (Murindo fault).

The area that has been selected as a dumping (see Figure No. 5.15 and Figure No. 5.16) has a depth at its eastern end of -24 m and on the west side of -26 m approximately, the morphology of the bottom is represented by an almost flat surface, with a slope not higher than 0.058 ° or 0.1% that slopes in the SEE - NWW direction. Since this slope is much smaller than the angle of repose of the sediments, there is

no possibility that these, once deposited on the seabed are going to move to another point from where they were deposited.

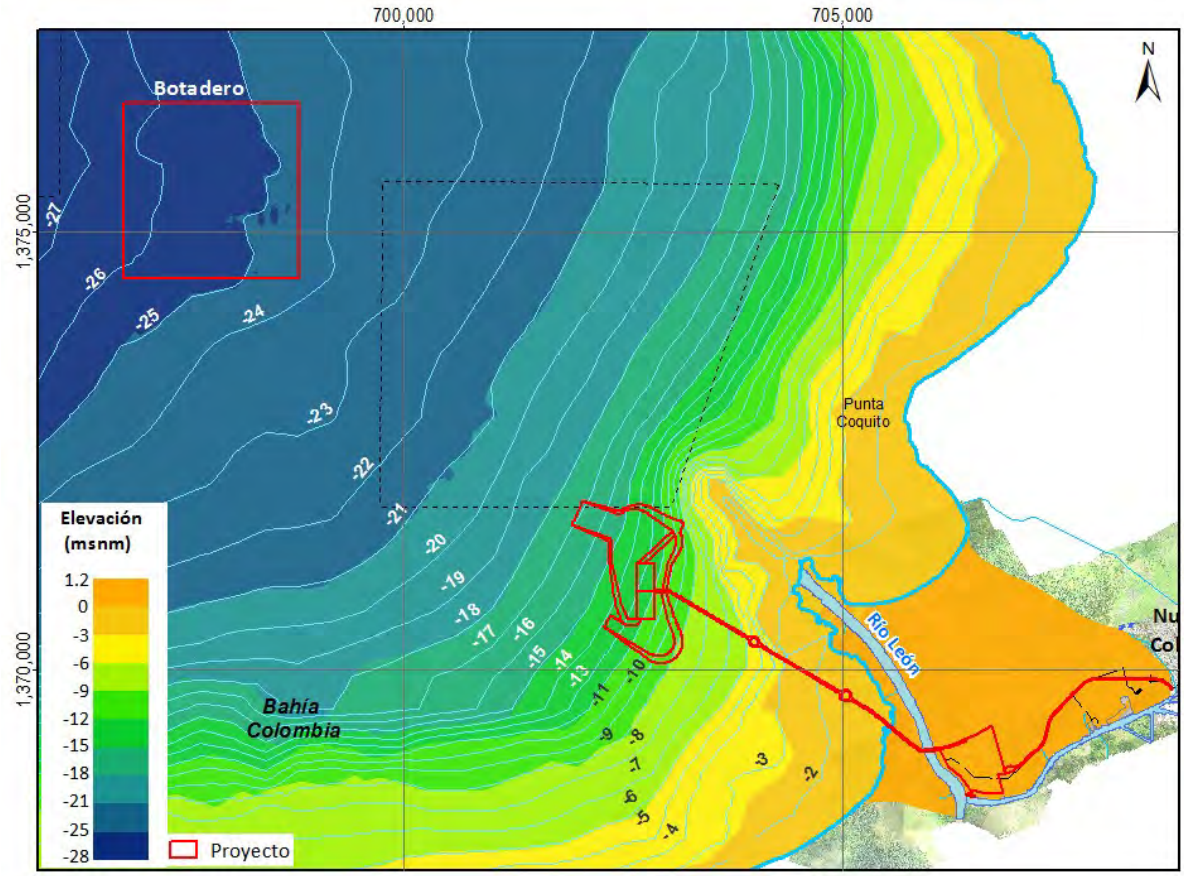


Figure No. 5.15 Bathymetric and elevation model of the study area
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

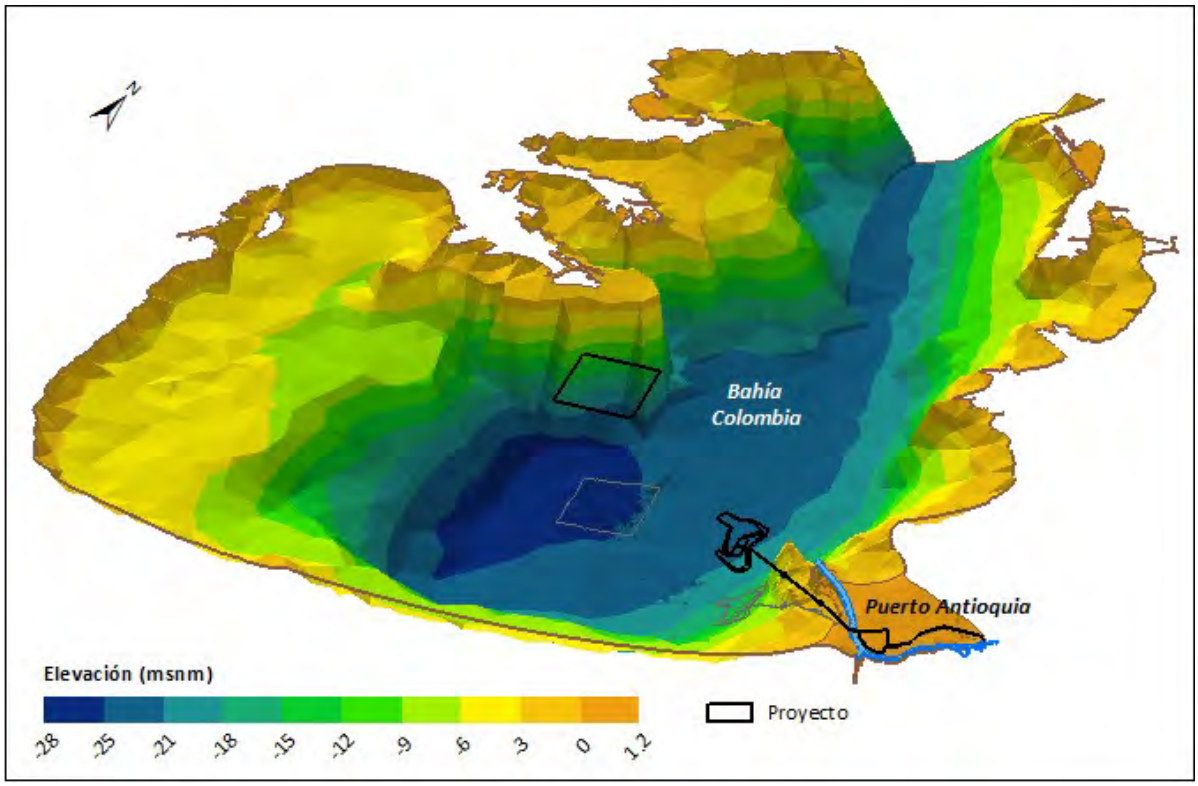


Figure No. 5.16 Bathymetric and elevation model of the study area
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Landscape unit*

The study area of the project, is located in an inter-Andean Fostos Geology (Atrato, Cauca, Magdalena), in a type of morphogenetic Rain Depositional environment that belongs to a Landscape of Lacustrine Rain Plain (P_F_2) and a type of flat flood relief and terrace with predominant rocks of lacustrine alluvial deposits, beach deposits as well as arcillites and sandstones.

Rain Lacustrine Plain Landscape (P_F_2)[25]

[25] AGUSTÍN CODAZZI GEOLOGICAL INSTITUTE - IGAC. General Survey of Soils and Land Zoning. Antioquia Department. Volume 1. Bogotá. Imprenta Nacional de Colombia, 2007. 992 p.

The Rain Lacustrine Plain Landscape and rain delta is located in the western low part of the Department of Antioquia, formed by Quaternary sedimentary rocks with small igneous intrusions very localized in fluviodeltaic floodplains.

- *Conclusions*

The zone of direct influence of the project is framed in the floodplains of the León River, the surface has a flat topography, whose local relief does not exceed one meter, are the result of the accumulation of sediments of recent age that have been transported by the drainages that run along the western flank of the Abibe Mountain Range

In the area, the lithological units are all of the sedimentary type, it is for this reason that there are not hard rock quarries that supply construction materials to the project in its surroundings, the nearest sources are associated with the rivers and can supply drag materials.

The Apartadó Fault (Uramita Fault), is approximately 13 km east of the project.

In accordance with the geological framework of the area where the project is located, threats were identified by flooding, by opening in the left bank of the river, lateral scour, sludge diapirism and earthquakes.

The project area shows a high threat due to earthquakes.

Currently, a process of lateral scour is affecting the property where the port facilities will be established. This threat, because of being active and occurring in the influence area of the project, is considered high.

In the project area there is also a strong interaction between anthropic activity and oceanic and fluvial processes at the moment, the combination of these processes added to the climate, has resulted in the current geomorphology of the area.

The units of the alluvial plain of the León River and the river delta, and their corresponding geoforms, were identified geomorphologically.

The mouth of the León River was diverted in 1989 in order to make navigation easier, however this deviation gave rise to a strong sedimentary process that is still active, which has resulted in a modification of the landscape, the bathymetric composition in the sea and therefore affecting navigation.

The delta of León river has been gradually moving year after year towards the sea, during a period of 25 years counted from 1989 to 2015, the body of sediments has moved approximately 2250 m.

It is likely that if the dredging operations are suspended, León river can change its mouth showing an opening on its left bank, which is the most fragile area.

The bathymetric configuration of the seafloor forms large areas with a very moderate inclination, which allows the disposal of dredged materials without forming protuberances, or that those are going to slide.

- *Recommendations*

Since the project area is in high threat due to earthquakes, it is recommended that the constructions be carried out within the framework of the Colombian Restructuring Earthquake Resistance (NSR-10), which indicates the buildings conditions so that the structural response to an earthquake is favorable.

Formulate the strategies and pertinent measures that allow to mitigate and control a phenomenon of lateral scour that is affecting the property where the port facilities will be established.

Bear in mind that the León River can break through its left bank and its mouth can be very close to the area where the viaduct will be built.

5.1.3 Landscape

The Area of Influence of the Project is in a Landscape of "Lacustrine Fluvial Plain"[26] with a type of flat relief made by floods and terraces with predominant rocks composed by deposits of beaches and Quaternary sediments with small igneous instructions.

The project is part of the coastal zone of the Gulf of Urabá, with an onshore strip, whose coastline is approximately 543 km of border, characterized mostly by a geomorphology associated with low and swampy coasts, which brings together landscaped elements of alluvial and onshore plains, flood and mangrove, with a horizontal to slightly inclined and whose origins are associated with sedimentation and erosion processes. The gulf is part of the Darien region of Colombia, which has conditions of high humidity, great diversity and fluvial depressions

[26] GEOGRAPHIC INSTITUTE AGUSTÍN CODAZI -IGAC. General Survey of Soils and Land Zoning. Antioquia Department. Volume 1, 2 and 3. Bogota: National Printing of Colombia, 2007. 992 p. DB -IGAC1-00869

The geomorphology units of the project have characteristics of erosive and accretive regimes, is comprised by alluvial plains named in Turbo POT, 2000[27] as Alluvial Plain Macro unit located in the flood plains of the Atrato - León River in the Western sector of the municipality which is also associated to the sedimentary contributions of the rivers and the Coastal Complex Macro unit which comprises a narrow strip parallel to the coastline in which there is oceanic influence and where is also influenced by agents such as rain, wind and anthropic, and its combination results in the current configuration of the coastline, dividing it into the following sectors: Caimán Nuevo-León River Sector, which has a length of 52 kilometers, in which low coasts of narrow beaches are combined with false cliffs, León River - Marirrío Bay Sector that has a length of 38 kilometers which limits the area of Bahía Colombia with narrow beaches (1-3 m), Marirrío Bay -Boca Tarena Sector which is characterized by the delta-shaped digitate formed at the mouth of the Atrato River, where the bays that are formed make together a coastline of around 100 km

- *Landscape Units*

The general landscape units with secondary information at a scale of 1: 550,000 and detailed at 1: 10,000 scale with secondary and primary information in the field are presented below.

- Landscape Units - General Scale 1: 550,000

According to the Turbo POT made in 2000, three (3) 1: 550,000 scale landscape units named Alluvial Plain with Wetlands, Offshore Plain with Wetlands and banana ranges are presented in the intervention area of the project (see Figure No.).

Alluvial Plain with Wetlands, they present very flat topographies, with flood plains formed by the overflow of the rivers, very thin sediments of predominant alluvial origin with high content of organic matter, patches of forests, it shows an anthropic intervention in the eastern sector of the unit in the surroundings of the Leon River, high sedimentation product of erosive processes upstream, it also shows a precipitation of the area of 4,000 mm/year and Afro-Colombian inhabitants predominance, which are provided from the fishing resource and extraction of wood, what makes them a population which is dependent on the environmental offer, therefore, it is an ecologically fragile and a strategic environment for the subregion.

Ofshore Plains with Wetlands, comprises approximately one kilometer inland from the coastline where there is an ecosystem defined by the sea-air-soil interaction with

[27] COLOMBIA. MUNICIPIO DE TURBO. Plan de Ordenamiento Territorial: diagnóstico físico-ambiental. Turbo: 2000. Libro 1. Parte 1. 71 p.

a rainfall of 4,000 mm/year. There are narrow beaches (between 1 and 3 m wide), behind the beaches there are areas flooded with organic material, there is a vegetation of mangrove species mixed with fern, palm trees and flooded pastures. Despite the fact that that the mangrove is forbidden, it has been used for fuelwood consumption, coal manufacturing, poles, shallows, piles, construction, among others which has involved the alteration of mangrove regeneration dynamics.

Bahía Colombia is strongly influenced by the sediments mainly coming from the León River, which has strongly affected the bathymetries, constituting a limitation for the draft of the ships that approach the area since it is an area where these vessels are anchored for export of banana produced in the area, so a constant dredging becomes necessary at the mouth of the river to ensure the navigability of the same for the fluvial-marine transit of the Banana Convoy

Banana ranges, have a rainfall rate of 2,500 to 3,500 mm/year with no plant cover, rainfall coupled with banana activity in this sector where the areas of river removal are not respected, streams are diverted and canals are made that end up being a conduit for the sediments, which caused a serious problem of lateral erosion at the margins of the rivers, affecting the crops and infrastructure settled on them. These factors, added to the predominant low slopes, produce a high flood threat for the areas near the riverbanks

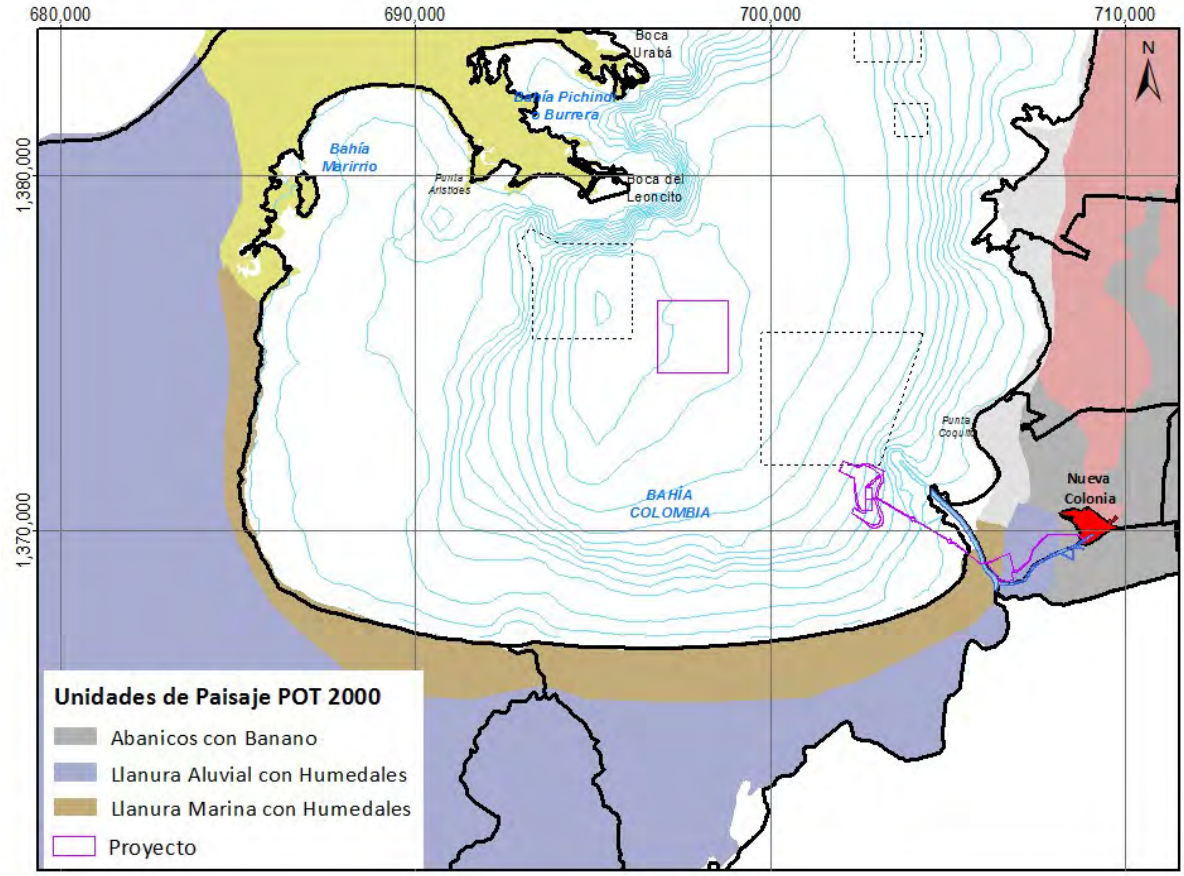


Figure No. Landscape units - scale 1: 550,000
Source: POT, 2000[28]

- Landscape units - Detailed scale 1: 10,000

The units of the landscape are geographical areas with a differentiated structural, functional or perceptual configuration, unique and singular, according to the characteristics that define it after a long period of time. They are identified by their internal coherence and their differences with respect to the other contiguous units, that is, the landscape units are areas of the territory that have a differentiated landscape character, which has been influenced by natural or anthropic factors[29].

As mentioned above, the landscape units for the project were identified from the superposition of layers of the dominant ecological factors that affect the structure and functional attributes of the ecosystem such as geomorphology, drainage network,

[28] COLOMBIA. MUNICIPALITY OF TURBO. Territorial arrangement planning. Prospective phase Map, Landscape units Scale 1: 550,000. Turbo, 2000
[29] GENERALITAT VALENCIANA - Regional Ministry of Infrastructure, Territory and Environment. Methodological guide Landscape study. Valencia Spain. Regional Ministry of Infrastructure, Territory and Environment Editorial, 2012. 172 p. ISBN 978-84-482-5690-2

vegetation cover and artificial territories. with the help of the Geographical Information System - SIG tool.

The methodology to obtain the limits of each unit of the landscape, was presented in the chapter of Generalities of the present study for the Modification of Environmental License for the Project of construction and Operation of a solid bulk cargoes Port Terminal in Bahía Colombia

The study area is located in a topography of the plains which generates less variations in the relief, the results of the units of the landscape were very influenced by the geomorphology comprised by alluvial plains as well as emerged delta plains and vegetation cover, these criteria being those who contributed the most in identifying the type of landscape units for the project.

As a result, 13 Landscape Units were identified in the study area of the project, which are presented in Table No. 5.1, Figure No. 5.18 and Figure No. 5.19 (see map MOD_LA_PTO_ANT_11_landscape), of which, the one that presented the largest landscape unit area was the so-called B-La (Alluvial plain forests), followed by the landscape unit Sea (Offshore water) and the ones of smaller area, the As-La units (settlements in alluvial plain) and B- Dn (Natural Dam Forest).

Table No. 5.1 Landscape units for the project study area

No Landscape Units	LANDSCAPE UNIT	NOMENCLATURE	AREA(ha)
1	Forests in natural dock	B-Dn	2.4
2	Forests in alluvial plain	B-La	153.5
3	Forests in the deltaic plain emerged	B-Lde	7.8
4	Crops in alluvial plain	C-La	11.2
5	Industries in alluvial plain	I-La	4.5
6	Sea	Mar	873.3
7	Pastures in alluvial plain	P-La	86.1
8	Pastures in emerged deltaic plain	P-Lde	7.0
9	River	Rio	15.4
10	Herbaceous vegetation in alluvial plain	V-La	69.8
11	Herbaceous vegetation in emerged deltaic plain	V-Lde	4.1
12	Urbanized areas	Zu	73.8
13	Urbanized areas in the alluvial plain	Zu-La	2.6

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

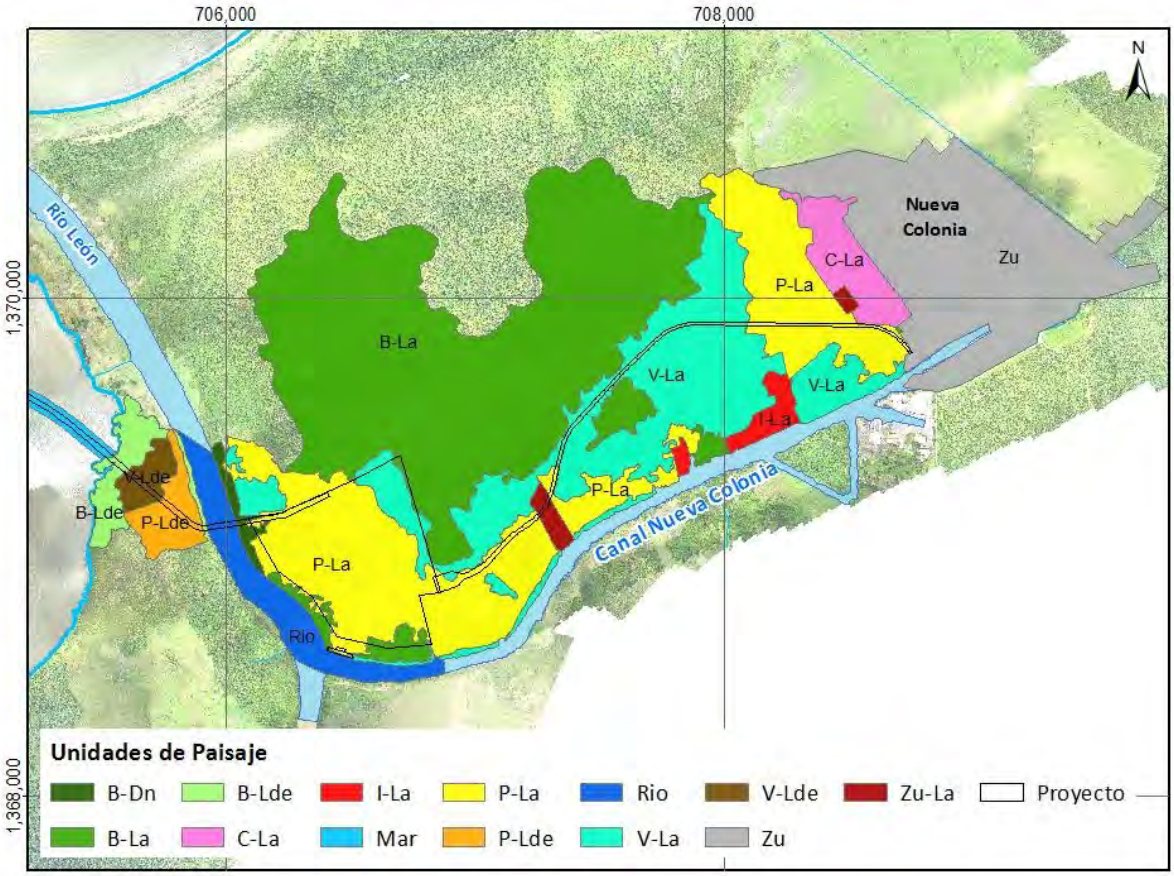


Figure No. 5.17 Onshore Landscape Units in the project study area
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

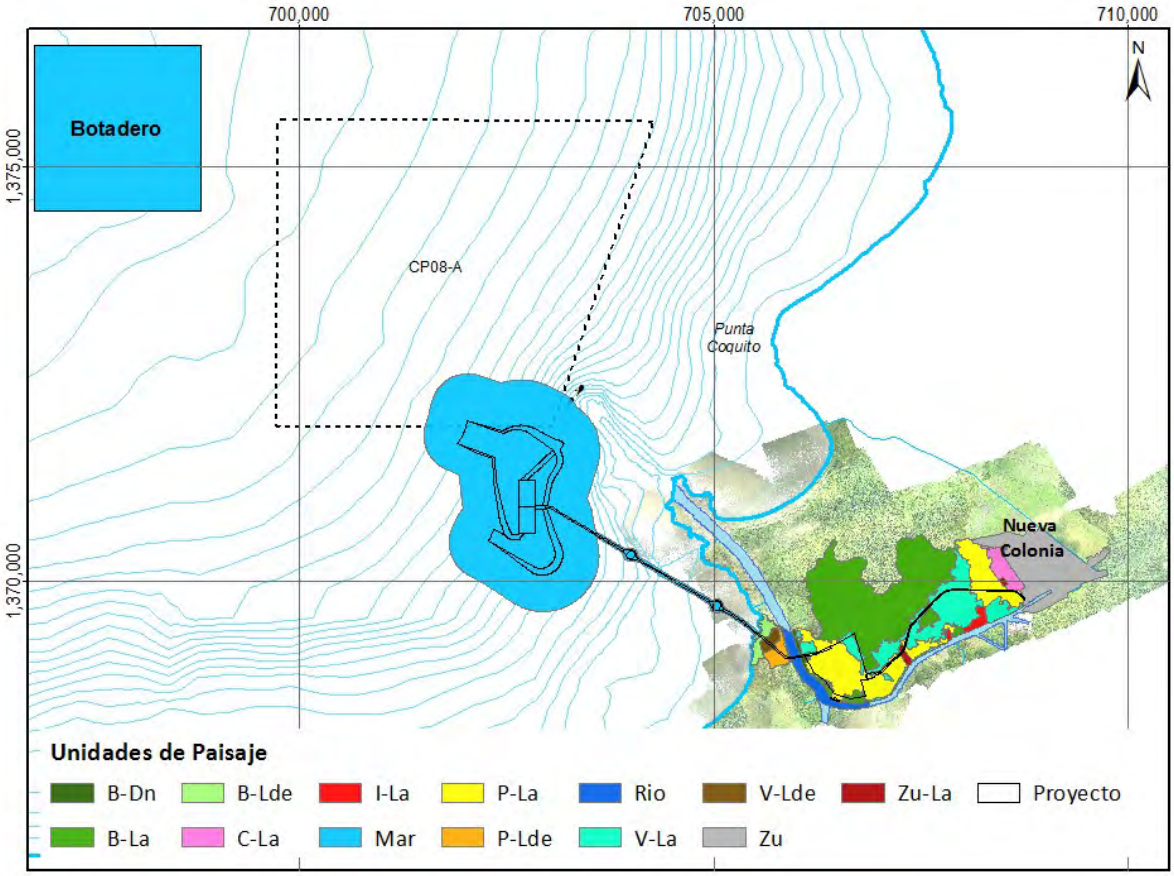


Figure No. 5.18 Offshore and Onshore Landscape Units in the project study area
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Description of the project within the landscape component of the study area*

The study area of the project is framed in several landscape units in the onshore and offshore area, with a medium capacity of changes absorption due to the predominance of a vegetative cover in it constituted by mangrove and gallery or riparian forest. It has been intervened. In addition, they are mostly flood areas, since a large percentage of the landscape units are present in a geomorphology of alluvial plain and emerged deltaic plain, which have a slope between 0 - 7%. The greater fragility of the current landscape is due to the possible modifications that are made to the geoforms with the works of the project

The project works (Onshore Terminal) that will be built mostly involves the landscape unit P-La (Pastures in alluvial plain) and lower proportion of V-La (herbaceous

vegetation in alluvial plain), which are units that have been intervened by men for different economic activities such as crops and livestock, where the project will not intervene large areas of natural vegetation coverage, however, the infrastructure that will be built in the study area will change the perception of the current landscape in the population .

For the construction of the viaduct, a strip of mangrove forest vegetation, which is part of the landscape unit B-Lde (deltaic forest in the Delta emerged) and in turn of the Protected Forest Reserve of the Wetlands between Suriquí and León rivers, should be intervened. It is worth mentioning that there are currently intervened sectors within the reserve, which has reduced the quality of the landscape due to anthropic actions.

The construction of the Dock (offshore terminal) in Bahía Colombia, the jetty, the bridge and catchment on the León River, can alter the landscape due to the new infrastructure in the project area and the possible temporary affectation of physicochemical and bacteriological contamination in the bodies of Water.

On the other hand, the marine landscape (sea landscape unit) in the dump area will be slightly changed due to the disposition of the dredging material to deepen the maneuvering areas and the access channel to the port in Bahía Colombia, since it will be increased the bathymetry in an authorized area for that purpose, without exceeding the minimum height for the navigability of the vessels in the Gulf of Urabá.

- *Landscape visibility analysis*

The analysis of the landscape visibility, refers to the clarity or degree of optical perception that observers have in front of the landscape in the study area, where the human values that refer to the relationship importance of the population of the scenic sites and the sensitivity of these sites with respect to the horizontal distance of the observers that travel along the trails, waterways and water network. It is worth mentioning that the topography of the area was not considered, since the geomorphology belongs to plains with little variation in altitudes.

To this extent, to proceed with the analysis of visibility of the landscape, the trails were identified, the existing road connecting the Nueva Colonia township to the project site, the Nueva Colonia canal to the mouth with the León River and the León River itself. the mouth to Bahía Colombia, since they are the sites with greater transits by the observers of the influence area, from which a visibility analysis was carried out according to the distances defined in the methodology: at 300 m, 1000 m and more than 1000 m, obtaining as a result the areas classified in the near, middle and far planes, as presented in Table No. 5.2 and Figure No. 5.20.

Table No. 5.2 Location of navigable waterways, trails and water network

Description	Length
Walking trails	211,0
Walking trails	151,9
Walking trails	381,0
Way to Nueva Colonia township – Bahía Colombia Urabá Port	3,906.0
Nueva Colonia Canal	3,125.0
León River (from the confluence of Nueva Colonia Canal to Bahía Colombia)	3,215.0

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

From the transit of the observers which can be in any part of the trails, roads, canal and river, the areas with greater and less visibility were generated from the point of view of the observers passing through the area of influence of the project, classified with a visual scale with horizontal distances according to the methodology shown in the chapter of Generalities of the present study

The results obtained for the area of influence of the project were influenced by the geomorphology of the area, which is comprised of alluvial plains and emerged deltaic plains where there are no representative variations in the altitude of the land, which implies greater horizontal visibility in the study area, therefore, the results with more area were classified in the far plane represented in an area of 857.2 Ha, for an average plane it was represented by 136.6 Ha and in a close plane which is the area that observers, at a distance of less than 300 m, have a visual represented in an area of 317.7 Ha, as can be seen in Table No. 5.3 and Figure No. 5.20 (see more detail in MOD_LA_PTO_ANT_13_Visibility)

Table No. 5.3 Results of landscape visibility analysis

Visual Scale	Description	Nomenclature	Area (Ha)
Far plane	Horizontal distance greater than 1,000 m	Pl	857,2
Medium plane	Horizontal distances> 300 m <= 1,000 m	Pm	136,6
Close plane	Horizontal distances <= 300 m	Pc	317,7

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

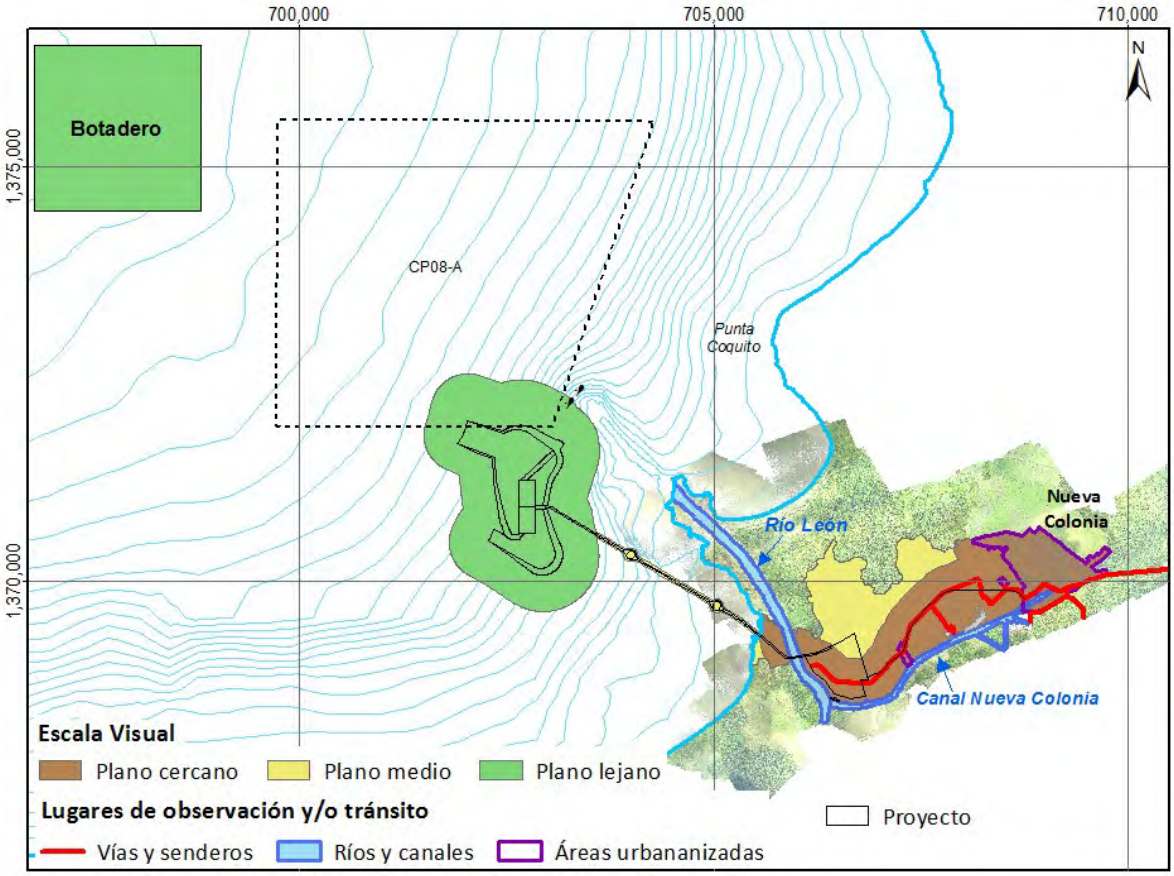


Figure No. 5.19 Landscape visibility analysis
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Visual quality of the landscape*

The quality of a landscape is understood by "the degree of excellence of this one, its merit not to be altered, destroyed or otherwise, its merit so that its essence and its current structure is preserved". Landscape, like any other element, has an intrinsic value, and its quality can be defined in terms of its intrinsic visual quality, the quality of the direct views that can be seen from it, and the scenic horizon that frames it, that is, it is the set of visual and emotional characteristics that qualify the beauty of the landscape[30].

[30] CISOURCES, P. The Visual Quality of Territorial Units. Application to the Tiétar river valley. Doctoral Thesis E.T.S. of Ing. de Montes. Polytechnic University, Madrid 1979.

For the assessment of the visual quality of the landscape, the methodology indicated by Montoya *et al*[31] was used, with modification in the scale of qualification of the proposed criteria, which were considered applicable for the analysis of visual quality and were also presented in the chapter on Generalities of the present study

The layers were made with their respective assessment according to the criteria for the abiotic and biotic natural formations such as the physiographic quality comprised by the altitude assessment, the quality of the vegetation cover comprised by the diversity of formations of the vegetation cover which is qualified according to the vegetation coverage of the study area as agricultural territories, herbaceous and / or shrub vegetation and the presence of forests, the absence or presence of water, additionally, artificial formations were considered as the degree of humanization as the presence of roads and urban centers.

Subsequently, the layers were superimposed by means of the Geographic Information System - GIS tool and categorized according to the scale of values and an adjustment was made in the sum of the criteria in order to balance the result when there are criteria that do not apply to all landscape units, which were classified into five (5) classes for the area of influence of the project in terms of visual quality and scenic integrity, as presented in Table No. 5.4 y Table No. 5.5.

[31] MONTOYA, Raymundo., PADILLA, Jorge., STANFORD, Sergio. Assessment of the quality and visual fragility of the landscape in the Valley of Zapotitlán de las salinas, Puebla (Mexico), 2003. In: Bulletin of A.G.E. No. 35, p. 123 - 136.

Table No. 5.4 Results of the classification of the Visual Quality of the Landscape Units for the project study area

Landscape Unit ID	ENVIRONMENTAL CRITERIA						Criteria evaluation	Criteria Percentage	Total Weighted	VISUAL QUALITY
	Altitude	Vegetable cover	Current land use	Presence of Water	Roads	Urban nuclei				
B-Dn	2	3	3	1	3	3	15	100%	15.0	High (It seems Unaltered)
B-La	2	3	3	1	2	3	14	100%	14.0	High (It seems Unaltered)
	2	3	3	1	3	3	15	100%	15.0	High (It seems Unaltered)
B-Lde	2	3	3	1	3	3	15	100%	15.0	High (It seems Unaltered)
C-La	2	1	2	1	2	3	11	100%	11.0	Moderate (mildly altered)
I-La	2	-	1	1	1	1	6	83%	7.2	Very low (very altered)
Mar	1	-	-	3	3	3	10	67%	15.0	Very high (Unaltered)
P-La	2	1	2	1	2	3	11	100%	11.0	Moderate (mildly altered)
P-Lde	2	1	2	1	3	3	12	100%	12.0	Moderate (mildly altered)
Rio	1	-	-	3	3	3	10	67%	15.0	Very high (Unaltered)
V-La	2	2	3	1	2	3	13	100%	13.0	Moderate (mildly altered)
	2	2	3	1	3	3	14	100%	14.0	High (It seems Unaltered)
V-Lde	2	2	3	1	3	3	14	100%	14.0	High (It seems Unaltered)
Zu	2	-	1	1	1	1	6	83%	7.2	Very low (very altered)
Zu-La	2	-	1	1	2	2	8	83%	9.6	Low (Moderately altered)

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Table No. 5.5 Areas of scenic integrity classification for the project study area

SCENIC INTEGRITY	NOMENCLATURE	AREA (ha)
Very low (very altered)	Mb	78.3
Low (Moderately altered)	B	2.6
Moderate (mildly altered)	M	167.7
High (It seems Unaltered)	A	174.1
Very high (Unaltered)	Ma	888.7

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

According to the results presented in Table No. 5.4 of the classification of landscape units in terms of visual quality and scenic integrity in Table No. 5.5, the following is a description of the results for the area of study of the project. Additionally, the results of the qualification of the landscape units in Figure No. 5.21 and in the map MOD_LA_PTO_ANT_12_QualityLandscape are graphically shown.

Class I, belongs to visual quality scenic integrity when it is very low. This classification belongs to the highly altered project areas with very homogeneous characteristics and little harmony in the environment, which were valued between 6 - 8 represented in 78.3 ha. The landscape units included in this class are Zu (Urbanized Areas) and I-La (Alluvial Plains Industries). The result is in agreement, since these units are the most intervened in the area of influence of the project, since they are the areas where the urban settlements of the Nueva Colonia township and the isolated dwellings of the El Canal district and the banana industries are located.

Class II belongs to the visual quality or scenic integrity when it is low. This classification belongs to the areas of the project moderately altered with natural elements with little harmony with the environment and becomes monotonous as a whole, which were valued between>> 8 - 10 represented in 2.6 ha. The landscape unit that belongs to this classification is Zu-La (Urbanized areas in the alluvial plain). They are areas that are intervened by isolated dwellings, located in very flat geomorphology and little altimetric variation, which is influenced by the constant floods by the same natural characteristics of the area.

Class III belongs to the visual quality or scenic integrity when it is moderate. This classification, which belongs to the slightly altered project areas, was valued between> 10 - 13, represented 167.7 ha. The landscape units included in this class are C-La (Alluvial Plains Crops), P-La (Alluvial Delta Plains Pastures), P-Lde (Extruded Deltaic Plains Pastures) and V-La (Alluvial Plains Herbaceous

Vegetation). They are areas intervened by man in smaller proportion, which are basically destined for crops, herbaceous vegetation and pastures.

Class IV belongs to the visual quality or scenic integrity when it is high. These ones are the areas of the project that seem unaltered were valued between> 13 - 15 represented on 174.1 ha. The landscape units included in this class are B-Dn (Natural Dam Forests), B-La (Alluvial Plain Forests), B-Lde (Forests in Emerged Delta Plain), V-La (Alluvial Plains Herbaceous Vegetation) and V-Lde (Herbaceous vegetation in the deltaic emerged valley). They correspond to a high visual quality due to the harmony of the elements with the environment and the current state of the same, since they are forested areas covered by mangrove cover or gallery or riparian forests with conservation use activity and recovery with some degree of intervention or less conserved natural state.

Class V belongs to the visual quality or scenic integrity when it is very high. Which are the areas of the Unaltered project were valued between> 15 - 18 represented in 888.7 ha. The landscape units included in this class are Sea (Sea) in Bahía Colombia and River (River) in the León River, these areas being the best from the point of view of visual quality due to the harmony of the elements and the current state of conservation in which it is found, which count on the banks with the presence of mangroves belonging to the Protected Forest Reserve of the Wetlands between the Suriquí and León rivers. It is worth mentioning that the rating is very high because the physicochemical and bacteriological quality of the waters of the river and the sea were not considered, which are turbidity waters due to the activity of the dredging of the León River and the Nueva Colonia Canal. the navigability of the same and guaranteed fluvial-marine transit of the Banana Convoy.

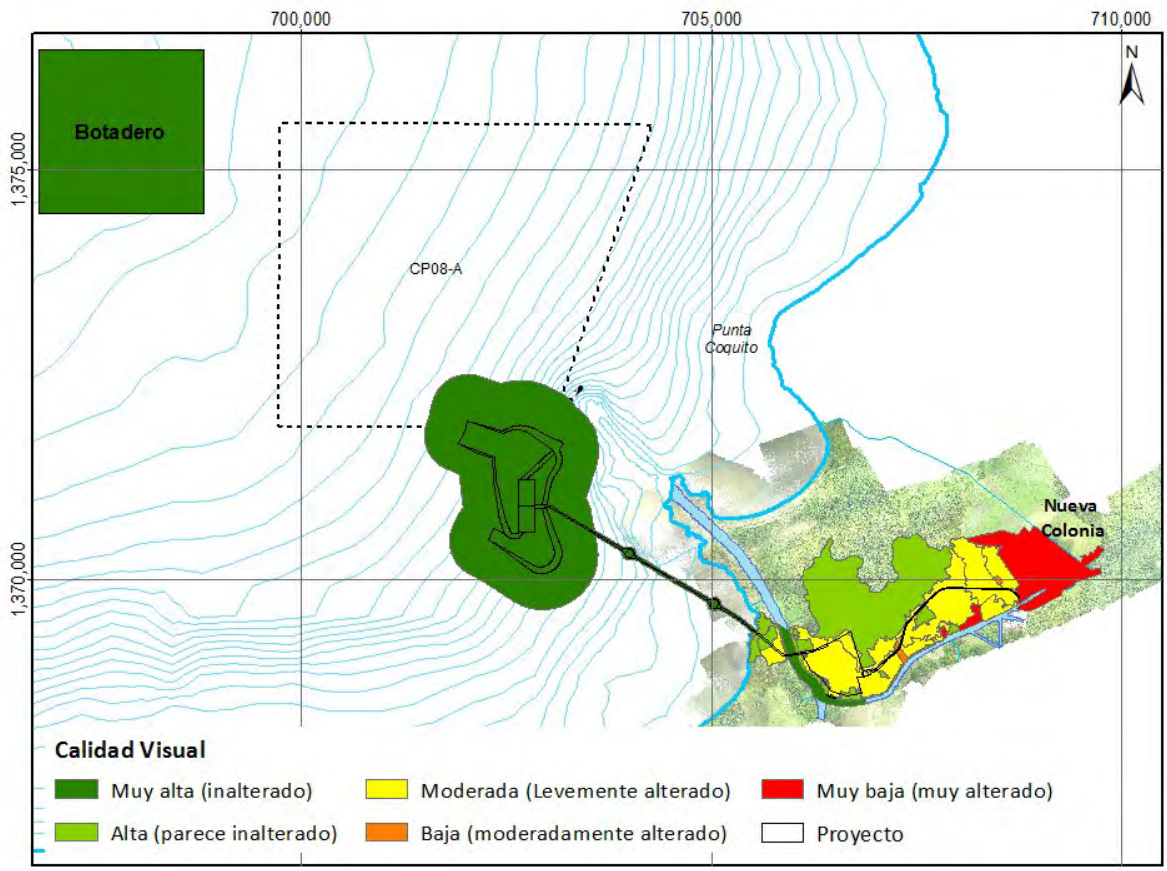


Figure No. 5.20 Visual quality of the Landscape Units
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Places of scenic interest*

As a result of the field trips and information provided by the community of the project study area, one (1) site was selected at the Nueva Colonia Canal Jetty, type area three (3) sectors at the mouth of the Nueva Colonia Canal to the León River, the mouth of the León River to the Gulf of Urabá as well as the vegetative cover of the mangrove and of linear type the footpaths and the existent route from Nueva Colonia to the port as places of scenic interest or scenic attractions, which are located in different sectors of the study area of the project.

The classification of the scenic attractions or sites of scenic interest, was made in accordance with the provisions of the chapter of Generalities in the landscape item, which establishes the classes in which the sites with scenic attractions can be found in accordance with the importance of the landscape based on human perception, hydrological characteristics, conservation status, vegetation cover and land use,

subdivided into three (3) classes: Deteriorated, Common or typical and Singular. Each scenic attraction was identified in their corresponding unit of landscape and the importance it has in its environment as well as the positive attributes they evoke in people.

Table No. 5.6 to Table No. 5.8 and Figure No. 5.22 show the location of sites of scenic interest or scenic attractions, sectors where they are located and their classification.

Table No. 5.6 Location and classification of the site of scenic interest - point type

No. Sites	Place of the site	Classification of the scenic attraction		Plan coordinates Magna Sirgas Origin Bogotá	
		Class	Nomenclature	X	Y
S1	Nueva Colonia Canal Jetty	Deteriorated	Dt	709.073,44	1.369.883,60

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Table No. 5.7 Location and classification of sites of landscape interest - type area

No. Sites	Place of the site	Classification of the scenic attraction		Area (ha)	Plan coordinates Magna Sirgas Origin Bogotá	
		Class	Nomenclature	X	X	Y
S2	Mouth of the Canal Nueva Colonia to the León River	Common or typical	Cm	2.6	706,410.85	1,368,537.41
S3	Mouth of the León River to the Gulf of Urabá	Singular	Sg	13	704,541.57	1,371,043.02
S4	Manglover (Protected Forest Reserve of the Wetlands between the Suriquí and León rivers)	Singular	Sg	6.9	705,572.81	1,369,196.26

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Table No. 5.8 Location and classification of sites of landscape interest - lineal

Place of the site	Classification of the scenic attraction		Length
	Class	Nomenclature	m
Access route of the Nueva Colonia township to the Bahía Colombia port of Urabá Project	Common or typical	Cm-P	3.906,5
Sederos	Common or typical	Cm-S	211,0
Sederos	Common or typical	Cm-S	151,9
Sederos	Common o typical	Cm-S	381,0

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

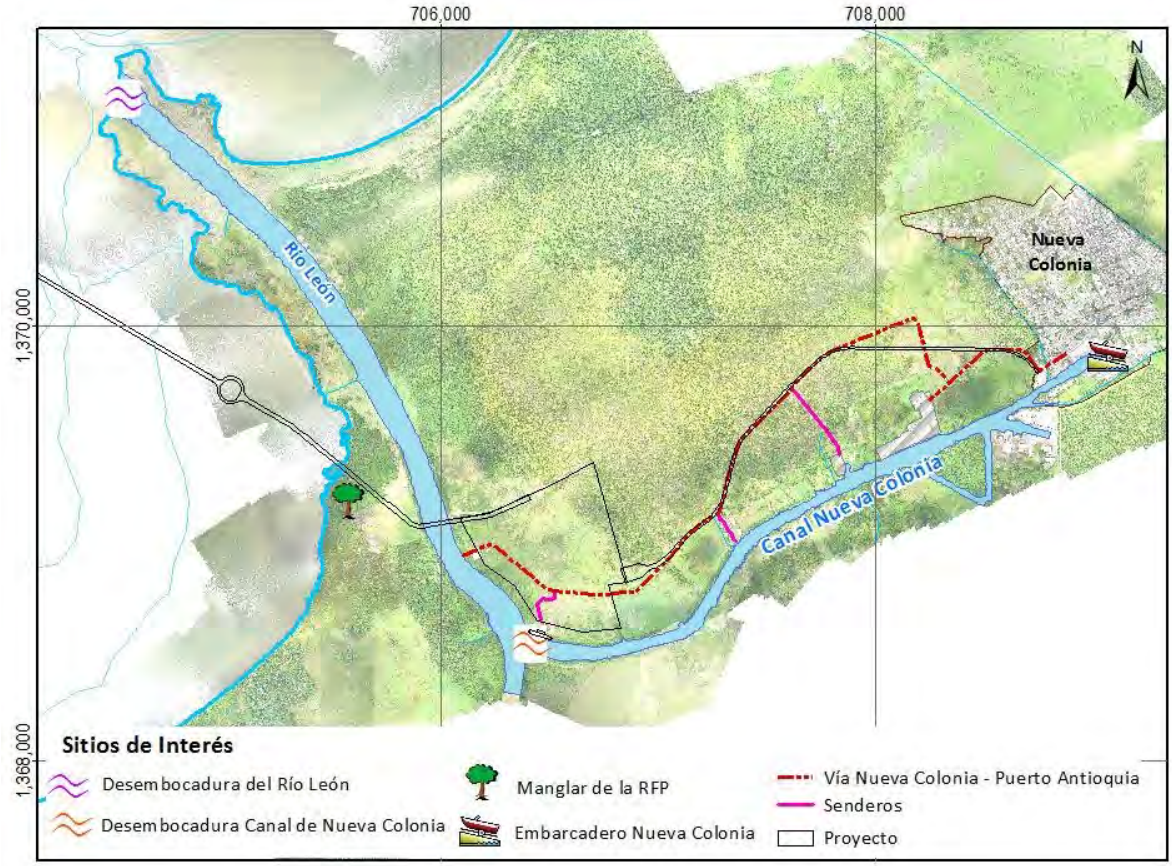


Figure No. 5.21 Scenic interest places location
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

The following is a description of the most relevant sites of interest in the study area and the classification according to the class as presented in Table No. 5.6.

- S1_Dt (Deteriorated) - Nueva Colonia Canal Jetty–Nueva Colonia township-

This site is recognized in the Nueva Colonia township as the main jetty for public use in the area (see Photo No. 5.10), which is the place where the boats are docked and the embarkation of the population whose economic activity is fishing takes place. These people perform their tasks in Bahía Colombia. The unit of the landscape to which it belongs is Cp_La (Center populated in alluvial plain)

Additionally, at the jetty the type of fluvial-marine transport (banana convoy) that carries out the transfer of banana export products produced in the area to the anchorage area authorized by DIMAR for the vessels can be observed, that is the

place in which the load of the production of the Convoy to the Ship maneuvers take place.

It is worth mentioning, that the site is a place with tourist potential but its current conditions are not the best, there was accumulation of water buchon duckweed and ordinary solid waste, causing a visual deterioration and unpleasant odors for people who circulate in the area, therefore, it was classified in the **Deteriorated** class **(Dt).**

Photo No. 5.10 Nueva Colonia Canal Jetty
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- S2_Cm (Common or Typical) Mouth of the Nueva Colonia Canal to the León River

It is framed in the flood plain of the León River and it was considered an area of scenic interest, due to the state in which the mouth of the Nueva Colonia Canal meets the León River, which has gallery and or riparian forests in a section of the canal channel and in another sector with clean pastures, which makes it a scenic attraction for the state of conservation in which it is located. The unit of the landscape to which it belongs is called River (León River)

The sector presents a natural landscape with wooded spaces, however the state of the water quality is not the best, since it shows high turbidity which is influenced by the sedimentary material dragging of the León River and additionally the canal is dredged constantly to maintain the navigability of it. The objective of the navigability of the canal is to guarantee the fluvial-marine transit of the banana convoys, which is a typical economic activity of the area, as presented in Photo No. 5.11.

To this extent, the mouth of the Nueva Colonia Canal to the León River is typical in many regions of the country, therefore it was classified in the **Common or Typical** class.

Photo No. 5.11 Mouth of Nueva Colonia Canal to León River
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- S3_Sg (Singular) Mouth of the León River in the Caribbean Sea - Bahía Colombia

The mouth of the Leon River to the sea has a flat topography, it is an area where you can see the confluence of the continental water with the Sea Water, generating a change in landscape terms, since the difference in flow, water turbidity, waves, fluvial and marine transport as the vessels that anchor in the authorized sector and the attack of the convoy to the vessel can be seen, this one belongs to the landscape units River (León River) and Sea (Sea Water), see Photo No. 5.12

According to the POT of the municipality of Turbo, 2000[32] this area is important because it is a sector of confluence between marine and continental waters, and everything that entails in ecological terms, is the base of the livelihood of Afro

[32] COLOMBIA. MUNICIPIO DE TURBO. Plan de Ordenamiento Territorial, 2000. Op cit.

Colombian communities associated with the fluvial and maritime activities and in the middle of it, to the mangrove: strategic ecosystem, fragile, exhausted and foundation of cultural representations of the Afro-Colombian communities.

Currently, at the mouth of the river to the sea there are large amounts of wood floating and trapped in the sediment, due to the low level of water that presents at the mouth, formed by the deltaic emerged and underwater plain bordering a delta front to the sea.

Therefore, the mouth of the León River in the Caribbean Sea - Bahía Colombia was categorized in the **Singular** class, because it is a scenic attractive with a different landscape from the others shown in the study area of the project.

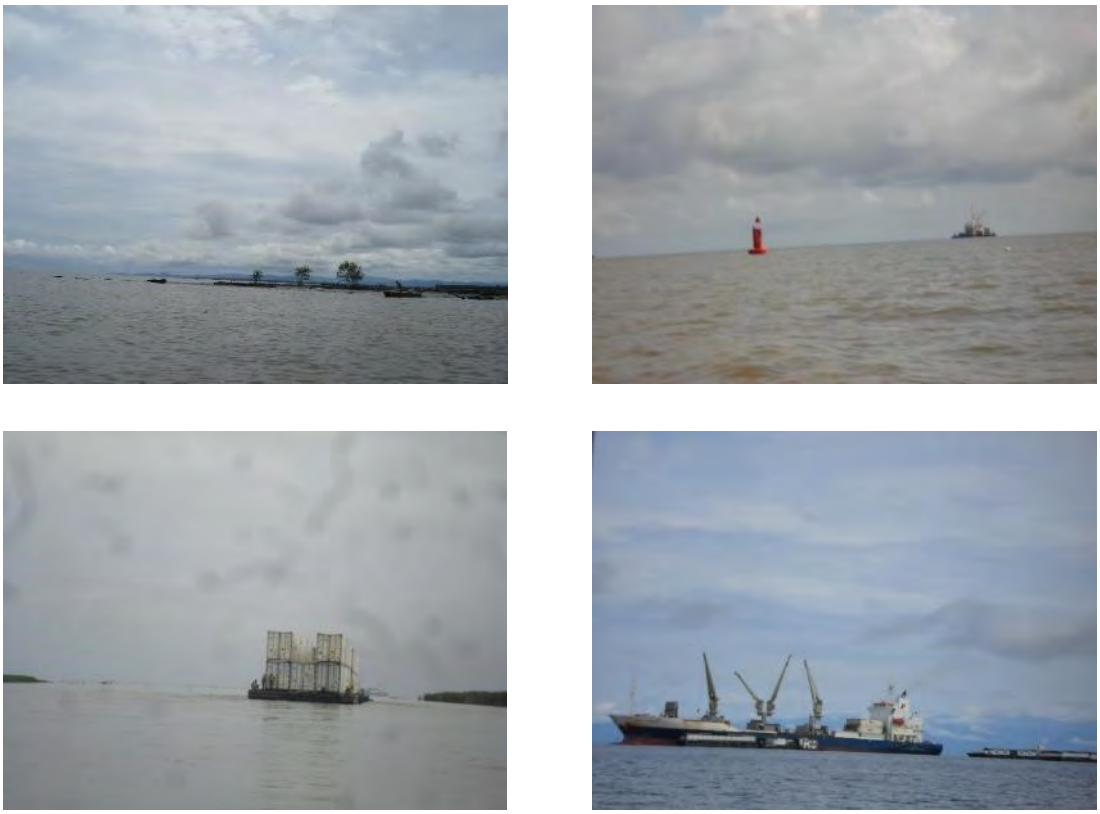


Photo No. 5.12 Mouth of León River to Bahía Colombia and anchorage area
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- S4 (Singular or typical) Mangrove (Protected Forest Reserve of the Wetlands between the Suriquí and León rivers)

The units of the B-Lde landscape (emerged deltaic plain forest), V-Lde (emerged herbaceous vegetation in the deltaic plain) and P-Lde (emerged deltaic plain pastures) identified in the influence area of the project, are part of the area of The Protected Forest Reserve of the Wetlands between the Suriquí and León rivers, which makes it a scenic attraction from the point of view of conservation, protection and ecological importance, are wetlands located in the Gulf of Urabá in the Tropical Humid Forest zone of life, this is located north-west of the Department of Antioquia, comprising the coastal municipalities of Turbo and Necoclí. The area is dominated by wetlands or marshes, where the vegetation known as panganales, arracachales stands out in association with a small mangrove swamp at the mouth of the river to Bahía Colombia.

It is worth mentioning that the area where the project is located on the left bank of the León River at the mouth of Bahía Colombia, shows an area with deforestation of the mangrove and the presence of grasses and herbaceous vegetation in the landscape units V -Lde (Herbaceous vegetation in emerged deltaic plain) and P-Lde (Pastures in emerged deltaic plain).

Photo No. 5.13 Mangrove (Protected Forest Reserve from the Wetlands between Suriqui and Leon rivers)
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- Cm (Common or Typical) Trails and track from Nueva Colonia - Bahía Colombia Port of Urabá Project Site

The existing road and trails in the project study area are in an alluvial plain with vegetal cover of clean grasses, plantain and banana plantations and a discontinuous urban fabric. It was considered as scenic attractions due to the current state of the same, since in its surroundings it is found with plant coverings and a Canal that connects the Nueva Colonia Canal in the settlement of the Vereda el Canal area,

used for its economic activity. Since they are so long, they cross several landscape units such as As-La (Alluvial plain settlement), V-La (Herbaceous vegetation in alluvial plain), B-La (Alluvial plain forest), P-La (Alluvial plain pastures), C-La (Crops in alluvial plain) and Cp-La (Center populated in alluvial plain)

These linear landscapes are corridors with low vehicular traffic which makes it attractive for the community using it for the displacement as a recreational area and ecological walks, it was categorized in the **Common or typical** class because it is a very frequent landscape in the area.

Photo No. 5.14 Trails and pathway Nueva Colonia township- Bahía de Colombia Port of Urabá Project

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- *Perception of communities as referents of their physical environment in cultural terms.*

The study area encompassed by the village El Canal and Nueva Colonia township at the municipality of Turbo are located in the Urabá Antioqueño, which is an area that has been characterized by cultural diversity, since the population is composed of diverse migratory processes and also by the mixture of the Paisa and its customs, the Chocoano, ther people of the coastal part of the county and of other departments and the afro descendant and indigenous ethnic groups, which have generated a whole new setting of specific cultural practices that enrich the multiethnic and multicultural manifestations that are there.

There are no recognized landscape sites at the municipal level, but the population has as cultural references sites where they can perform different recreational activities, cultural entertainment, parties for the integration of the population and family spaces, such as the Futsal fields that are in the Educational Institution Nueva Colonia Caribbean branch and Educational Institution 29th November, Kindergarten,

children's playground, soccer field, churches and the New Colonia Public Library (see Photo No. 5.15)

Photo No. 5.15 Cultural sites in the township of Nueva Colonia - Municipality of Turbo
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

- Offshore background landscape

The study conducted by IDEAM et al. (2007)[33], defines the marine landscape as an extension of the seabed, perceived in a spatial and temporal context, which has particular characteristics based on its structure or marine geoforms; for its classification the study incorporated the guidelines proposed by the working group of Marine Ecoregions of the World (MEOW), because it is a relatively recent topic and many terms can be ambiguous.

A part of the project is located in the offshore area, such as the dump for the disposal of dredged material, the maneuvering area for boats, the marine dock, access channel and the viaduct, which are framed within the province of the Caribbean Sea.

[33] IDEAM, 2007. Onshore, coastal and Offshore ecosystems of Colombia. Op cit.

in the Caribbean Ecozone continental shelf with a landscape of sandy platform and sandy mud platform of the Atrato Ecoregion (see Figure No. 5.23).

Atrato Ecoregion: Sandy platform (4pa-at) and sandy mud platform (4po-at)

The Atrato Ecoregion is strongly influenced by the discharges of the Atrato River located to the Northwest of the project. The waters of this sector are little agitated, turbid and of reduced salinity by the influence of the onshore tributaries present in the Bay. The platform has a predominance of sandy mud (4po-at), with sandy strips near the coast (4pa-at). The coast is low, goodly flanked by swamps with well-developed vegetation, where coverages with mangrove and secondary vegetation can be seen.

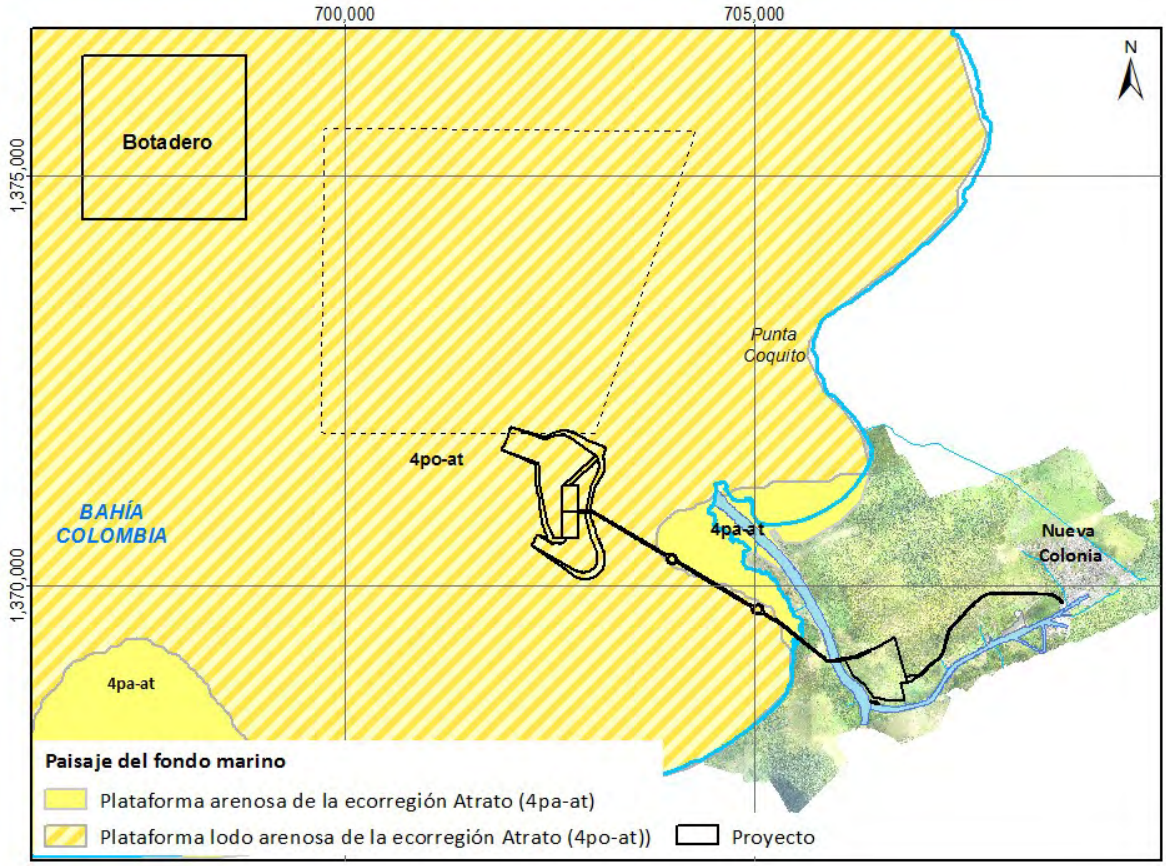


Figure No. 5.22 Offshore bottom landscape
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 de INVEMAR [34]

5.1.4 Soils and land use

Soil is the result of the interaction of formative factors such as climate, relief, parent material, organisms and time; and of formation processes such as weathering, leaching, salinization, among others. Therefore, the knowledge of the soils constitutes the decisive step to determine the potential, the aptitude, the restrictions and the limitations for the multiple use of the lands. For the case of the influence area of the project, the main factors forming the soil correspond to the parent material, the geomorphs of the land (Photo No. 5.16) and the climate. The soil is

[34] INSTITUTE OF HYDROLOGY, METEOROLOGY AND ENVIRONMENTAL STUDIES - IDEAM, INSTITUTO GEOGRÁFICO AGUSTÍN CODAZZI - IGAC; INSTITUTE OF RESEARCH OF BIOLOGICAL RESOURCES ALEXANDER VON HUMBOLDT - IavH; INSTITUTE OF MARINE AND COASTAL INVESTIGATIONS JOSÉ BENITO VIVES DE ANDREIS - INVEMAR; INSTITUTO AMAZÓNICO DE INVESTIGACIONES CIENTÍFICAS SINCHI -I.SINCHI; INSTITUTE OF ENVIRONMENTAL RESEARCH OF THE PACIFIC JHON VON NEUMAN - IIAP. Onshore, coastal and offshore ecosystems of Colombia. Sheet 12 of 36. Scale 1: 500,000. [Online] <http://www.invemar.org.co/portal_old/noticias.jsp?id=3458&idcat=104> [Last checked 24, July, 2015]

thus determining for the development of some of the most important economic activities in the area, such as agriculture and livestock.

Photo No. 5.16 Overview of the influence area of the project
Source: PIO S.A.S, Puerto Bahía Colombia de Urabá S.A.

The cartographic units of the soils identified in the influence area of the project (see Figure No. 5.24 and map MOD_LA_PTO_ANT_14_Soils) are located on the very humid warm and humid warm climate and are described in the soil legend, which is presented in the Table No. 5.9.

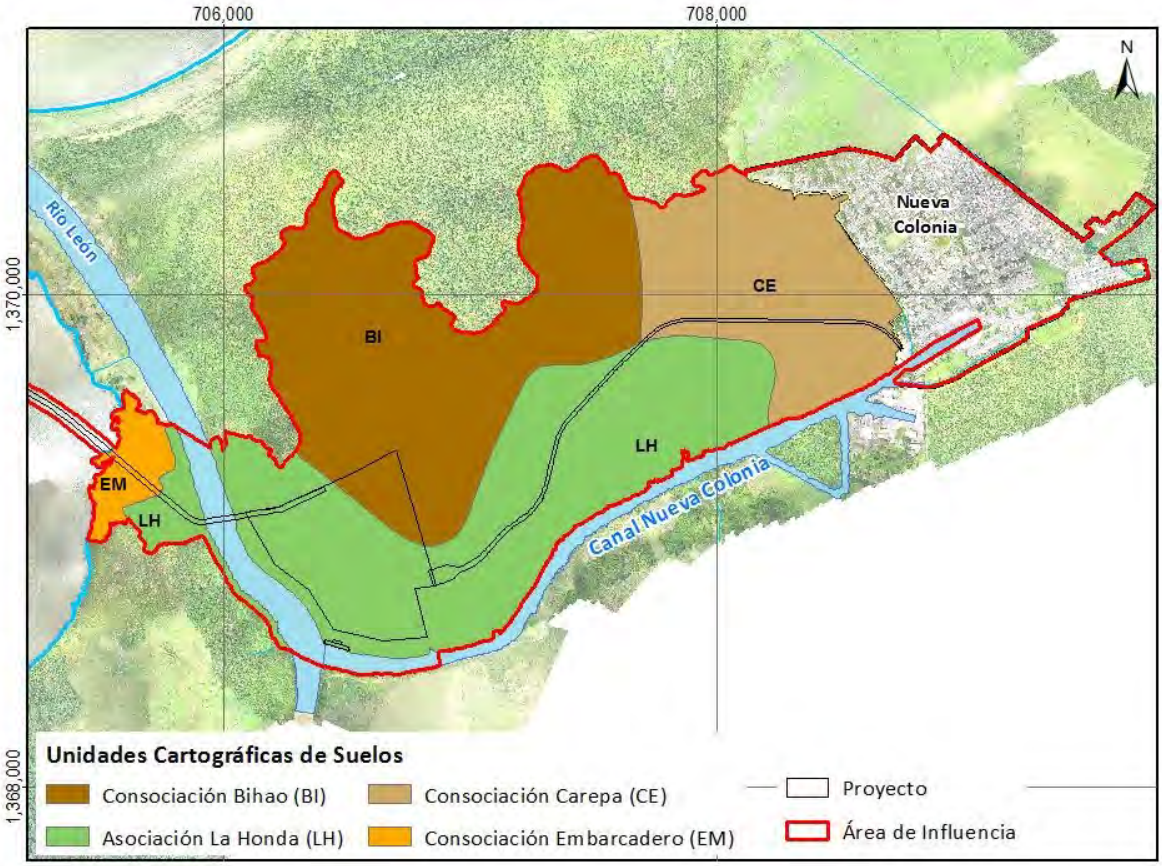


Figure No. 5.23 Soil Cartographic Units (also Known as UCS) in the Influence Area of the project

Source: Aqua & Terra Consultores Asociados S.A.S, 2015.

Table No. 5.9 Legend of soils in the influence area

Description					Taxonomy							
Weather	**Landscape**	**Relief type**	**Shape of the land**	**Lithology and/or sediments**	**Order**	**Sub order**	**Big group**	**Sub group**	**Name UCS**	**Symbology**	**Phases**	**Area (Ha)**
Warm, very humid	Plain	Flood plane	River flood active plan of Mendric	Deposits of organic matter with fine sediments.	Histosol	Hemists	Haplohemists	Hydric Haplohemists	BIHAO CONSOCIATION	BI	a	154,9
				Mixed alluvial sediments and lacustrine current and recent	Entisol	Aquents	Fluvaquents	Fluvaquentic Endoaquepts	LA HONDA ASSOCIATION	LH	a	136,8
Warm wet	Alluvial plain	Terraces		Mixed alluvial sediments	Inceptisol	Udepts	Eutrudepts	Fluvaquentic Eutrudepts	CAREPA CONSOCIATION	CE	a	69,8
	Marine plain and fluvial marine	Tide plane	Fluvial marine deltaic plane, delta	Mixed deposits (silt and sand) mixed with organic matter.	Entisol	Aquents	Fluvaquents	Typic Fluvaquents	JETTY CONSOCIATION	EM	a	11,1
Urban Area (Populated Center - New Colonia)										ZU		74,1
Water Body (León River)										CA		12,5

Source: IGAC, adapted by Aqua & Terra Consultores Asociados S.A.S, 2015.

- *Soils of the lacustrine flux plain and alluvial plain located in a very humid warm climate*

These soils have been developed on a single type of relief classified as floodplain, with slopes varying in percentage from 0 - 3% slightly flat, with altitudes between 0 - 50 m; the climate is very humid warm, it corresponds to the zone of life according to Holdridge to Tropical Humid Forest (bh-T).

In general, the parental materials that have given rise to the soils correspond to unaligned quaternary deposits of alluvial and / or colluvial origin, they are constituted by sediments of fine textures such as silts and clays, on the banks of the León river decomposing organic matter can be appreciated (Photo No. 5.17). The geoform is subject to flooding and prolonged waterlogging, closely related to the winter season

Photo No. 5.17 Thin textures soils with deposits of organic matter
Source Aqua & Terra Consultores Asociados S.A.S, 2015.

- Bihao Consociation (BI)

The unit is geomorphologically located in the plain of lacustrine and alluvial rain origin and the type of relief is the floodplain. The relief is flat to slightly flat, with slopes lower than 3%. The unit is affected by periodic and prolonged flooding and waterlogging. Soils have developed from fine alluviums and culminations of organic matter; they are superficial, limited by the fluctuating phreatic level that remains near the surface; the textures are medium and fine and the fertility is high. This cartographic unit within the study area conserves natural vegetation, with species of palm (Euterpe oleracea), fern (Acrostichum aureum) and Canna indica, forming the

palm cover also called "Naidizales". This soils unit covers an area of 154.9 hectares within the influence area of the project.

The consociation is made up of 75% Hydric Haplohemists soils; there are inclusions of Typic Endoaquents (20%); the remaining 5% are play on areas.

It is represented by the phase:

BIa: Bihao consociation, flat phase

- La Honda Association (LH)

This unit appears in the landscape of the Alluvial Plain overflowing the León River, which runs through a flat plain, which causes flooding due to lateral overflow and determines a selective sedimentation pattern, which leads to the formation of an incipient natural dam and an extensive basin or decantation bucket (lacustrine) with organic materials and clay minerals.

Soils have been developed from recent and current heterometric alluviums; they are very shallow to moderately deep, limited by fluctuating water table, poor to imperfectly drained, affected by periodic flooding.

Most of these lands within the influence area is used for pastures with natural or planted pastures, conserving natural vegetation on the banks of the León River and the Nueva Colonia canal, covering an area of 136.8 hectares (Photo No. 5.18).

The Association is formed by the Fluvaquentic Endoaquepts (40%), Aquic Udifuvents (30%) and Aeric Fluvaquents (30%) soils.

The phase was delimited:

LHa: Honda Association, flat phase.

Photo No. 5.18 Soils belonging to La Honda Association
Source: Aqua & Terra Consultores Asociados S.A.S, 2015.

- *Floors of the alluvial plain in warm humid climate*

The soils in this climate are located continuously to the town center of the Nueva Colonia township, within the influence area. At the height of 0 to 50 masl, temperature higher than 24ºC and precipitation of 3,000 to 7,000mm, it is classified in the Tropical Rainforest (Holdh) life zone (bh-T). The type of relief includes floodplains and terraces, in slightly flat relief with slopes 0-3%, with frequent flooding and waterlogging during the winter season. The soils have been caused by heterometric alluvium.

- Carepa Consociation (CE)

The unit occupies the landscape of plain of alluvial origin and lacustrine flux and the type of terrace relief, with slopes of less than 3%. The parent material that gives rise to the soil is composed of mixed alluviums; they are moderately well drained to poorly drained, of thin to medium textures, moderately deep to shallow and moderate fertility.

These soils within the study area are dedicated to semi-intensive livestock with natural and introduced pastures. plantain and banana crops are observed in the adjacent properties to the town center of the Nueva Colonia district. The natural vegetation is conserved in a minimal proportion; this unit covers an area of 69.8 hectares

The consociation is composed by 60% of soils with high saturation of bases (Fluvaquentic Eutrudepts) and in 25% for poorly drained soils (Fluvaquentic

Endoaquepts), inclusions are formed by Vertic Endoaquepts (10%) and Typic Udorthents (5%).

It is represented with the phase:

CEa: Carepa Consociation, flat phase

- *Soils of marine plain and marine fluvium in humid warm climate*

This unit is located near the coast of the Caribbean Sea, in the deltas of unit is located in humid warm climate, it is formed by marine morphogenetic environments, fluvial-marine, lacustrine and alluvial fluvium; belonging to the relief type of tidal plane. It has an altitude that varies between 0 - 15 masl, temperature higher than 24°C and precipitation of 2,000 to 3,000 mm

- Jetty Consociation (EM)

This unit is located near the coast of the Caribbean Sea, in Bahía Colombia, in the delta of the León River and in sectors that are far from the coastline, but with the influence of salt water. In humid warm climate, within the life zones (Holdridge) tropical moist forest (bh-T).

The Tidal Plane occupy low and swampy areas that occur near the coast line of Bahía Colombia with the influence of salt waters. Covered by mangrove vegetation and areas that have been highly intervened to become paddocks with planted pastures for livestock use; This unit of land has an area of 11.1 hectares within the influence area of the project.

These areas are continuously flooded by the rhythm of the tides and the soils that are formed as a result of marine flux sedimentation of organic material and minerals composed of clays and silts strongly mixed and subjected to sedimentation processes. The resulting landforms are marshes (mangroves) and swampy areas (lagoon deposits). The relief is flat and slightly flat, with slopes 1-3%. They are flat concave surfaces that remain flooded by the ebb and flow of the tides and have hydrophilic vegetation cover. These areas are continuously flooded by the rhythm of the tides and the soils that are formed as a result of marine flux sedimentation of organic material and minerals composed of clays and silts strongly mixed and subjected to sedimentation processes. The resulting landforms are marshes (mangroves) and swampy areas (lagoon deposits). The relief is flat and slightly flat, with slopes 1-3%. They are flat concave surfaces that remain flooded by the ebb and flow of the tides and have hydrophilic vegetation cover.

These soils have evolved from mineral and organic sediments of fluvial and marine origin; they are very superficial, with very poor natural swampy drainage and do not show pedogenetic development. In the mineral layers, fine textures dominate, sometimes with a sandy substrate. The dominant vegetation is the mangrove, which is subject to heavy exploitation; also species of arracacho, aeneas, lotus and water hyacinth are observed. These areas are a refuge for crabs (Photo No. 5.19), jaibas and other wildlife species.

Photo No. 5.19 Crabs in Mangrove Coverage
Source: Aqua & Terra Consultores Asociados S.A.S, 2015.

The cartographic unit is made up of Typic Fluvaquents soils by 75%, the remaining 25% corresponding to Hemic Haplofbrists soils.

The delimited phase is:

EMa: Consociation Jetty, flat phase.

- *Capacity and potential use of the soil*

The most important objective of the agrological analysis of the lands, after knowing the soils of an area and the distribution pattern in the spatial dimension, is the definition of the capacity of use and management of the land in such way that the

agricultural development, livestock and forestry, as well as actions aimed at the conservation, preservation or restoration of the natural environment, are executed in accordance with the aptitude and protection requirements when they are vulnerable to the action of environmental factors and human activity.

The system of land classification by capacity of use groups the soil units that have the same physical and chemical limitations, for their use and respond, therefore, to similar management practices. The system is structured in such a way that as the class increases by agrological capacity, the potential of the soil to produce decreases, and the need to conserve and protect the soil resource increases.

In Table No. 5.10 the classes and the agrological subclasses are related to the soil cartographic units (UCS) that make up the area of influence of the project. The potential use of the area of influence of the project is presented on the map MOD_LA_PTO_ANT_15_UsoPotencial.

Table No. 5.10 Agrological classes and subclasses of the soil cartographic units of the influence area of the project

UCS	Phases	Name UCS	Class	Subclasses	Main limitations of use	Potential use
CE	a	CAREPA CONSOCIATION	2s	2s-2	Low content of organic matter and phosphorus	(CSPS): semi - permanent and semi - intensive crops. With commercial crops such as banana, banana, cocoa, rice, oil palm and fruit trees and for livestock with improved pastures.
LH	a	ASSOCIATION LA HONDA	5hs	5hs-4	Frequent floods of long duration, superficial phreatic level, and very poor drainage.	(PIS): Intensive and semi-intensive grazing. Livestock with improved pastures and / or rice crops
EM	A	PIER CONSOCIATION	8h	8h-3	Floods or frequent long-term flooding Influence of tides, very poor drainage, high water table.	(Fp): Forestry protector. Conservation and protection of the diversity of the fauna and flora
BI	a	BIHAO CONSOCIATION	8h	8h-4	Flooding or frequent long-term flooding, very poor drainage High ground level, very shallow effective depth.	

Source: IGAC, adapted by Aqua & Terra Consultores Asociados S.A.S, 2015.

- Subclass 2s-2 (CSPS)

It includes the Cea unit of the Carepa consociation, with a warm humid climate of relief terraces. The dominant soils have developed from mixed alluvial sediments, are deep, well drained, fine texture, moderately acidic reaction and moderate to high fertility.

These lands have slight limitations due to moderate acidity, low phosphorus content and organic matter and poorly distributed rains that cause traumas to commercial crops.

These soils are suitable for intensive and semi - intensive agriculture (Figure No. 5.25) with commercial crops such as bananas, plantains, cocoa, rice, palm oil and fruit trees and for livestock with improved pastures. Most of these lands allow the use of agricultural machinery, require agronomic practices such as the application of fertilizer according to the content of nutrients in the soil and the needs of the respective crop. The management of pastures and livestock must be based on proven technological principles.

- Subclass 5hs-4 (PIS)

This subclass corresponds to a very humid warm climate, it is formed by the LHa soil unit of the Honda association; occupies the geomorphological position of the floodplain of the alluvial plain of the León River and the Nueva Colonia canal.

The relief is flat, with slopes that do not exceed 3% supports periodic flooding of long duration. Soils which have developed from alluvium are very shallow, limited by fluctuating water table, imperfect to poorly drained, moderately acid to slightly acidic reaction and moderate fertility.

The limitations are given by excess moisture that affect these lands for long periods of the year, making the potential use of these soils limited to intensive and semi - intensive grazing with improved pastures as long as the land is not flooded or the crop of rice (Figure No. 5.25).

- Subclass 8h-3 (Fp)

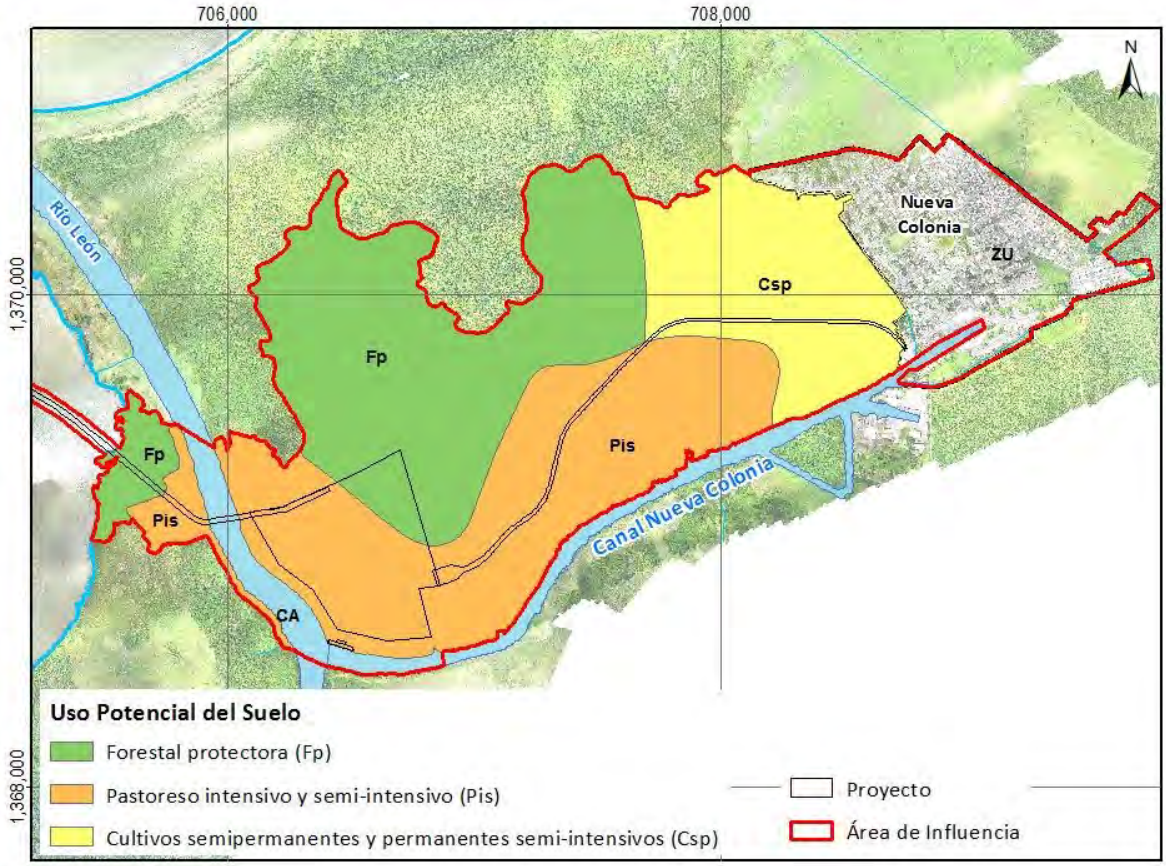
The soils that make up this subclass correspond to the EMa phase of the Jetty Consociation located in humid warm climate, it occupies the position of tidal plane next to the coast of the Caribbean Sea in Bahía Colombia and in the delta of the León River and sectors far from the coast but with influence of salt water. This subclass has a severe limitation due to the frequent and prolonged floods caused by the action of the tides. Due to the severe limitation, due to the excessive and permanent humidity caused by the surface phreatic level, these lands are not suitable for agricultural or forestry operations, therefore, they must dedicate themselves to the conservation and protection of the diversity of the existing fauna and flora, mainly the mangroves (Figure No. 5.25).

- Subclass 8h-4 (Fp)

This subclass corresponds to the BIai phase of the Bihao Consociation, located in the very humid warm climate; occupies the geomorphological position of floodplain in the plain landscape.

The relief is flat and slightly flat with slopes less than 3%. Soils have been developed from thin sediments and organic matter deposits; they are very shallow and limited by the water table, the natural drainage is poor to marshy textures which are medium and thin, buried by a little decomposed organic material, fertility is high.

This subclass has severe limitations for natural drainage and almost permanent surface water table. Most of these lands conserve the natural vegetation, finding species of arracacho, palms, buchon, cortaderas, ferns, gramalote, bihao and platanillo, among others. Due to the severe limitation that the unit presents due to excess moisture, these lands must be dedicated to the conservation of the existing fauna and flora (Figure No. 5.25).



Potential land use

Protective forest (Fp)

Intensive and semi-intensive grazing (Pis)

Semi-intensive permanent and semi-permanent cultivation (Csp)

Project

Area of influence

Figure 5.24 Potential land use in the project's area of influence
Source: *Aqua & Terra Consultores Asociados S.A.S* (2015)

- *Land use*

Land use is associated with a variety of characteristics regarding geomorphology and cover, and to a large extent depends on the area's environmental endowment and the socio-economic situation of the population that surrounds it. In general terms, these factors determine the methods and practices involved in its use.

According to the Land Use Plan (LUP) for the municipality of Turbo[35], the current use of and primary economic activity in the project's area of influence is agriculture for banana and plantain cultivation. It is bordered to the south by wetland areas, as shown in Figure 5.25.

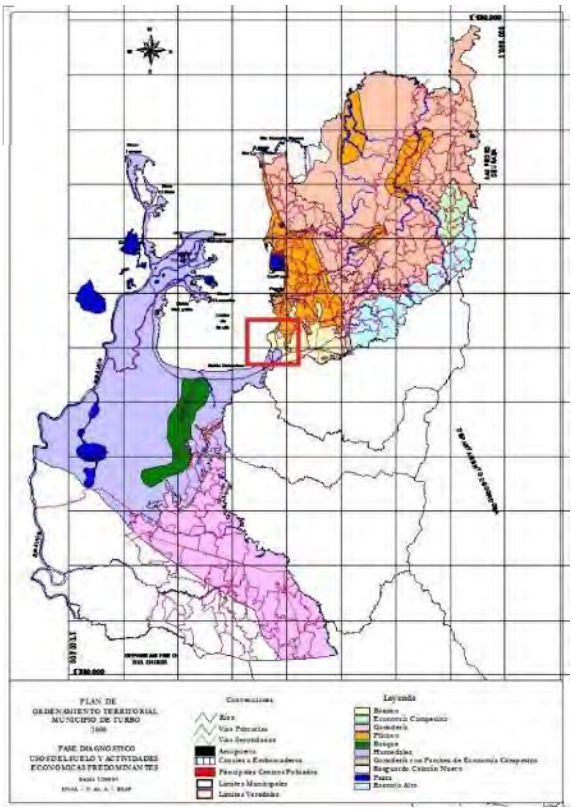


Figure 5.25 Primary land use and economic activity in the municipality of Turbo
Source: Turbo LUP (2010)[36]

Following the creation of the base line and in-field verification, six (6) land use types were found within the project's area of influence, as shown in Current Use

Protective forest (Fp) Intensive and semi-intensive grazing (Ps) Project

Restoration (Rc) Bodies of water (CA) Area of influence

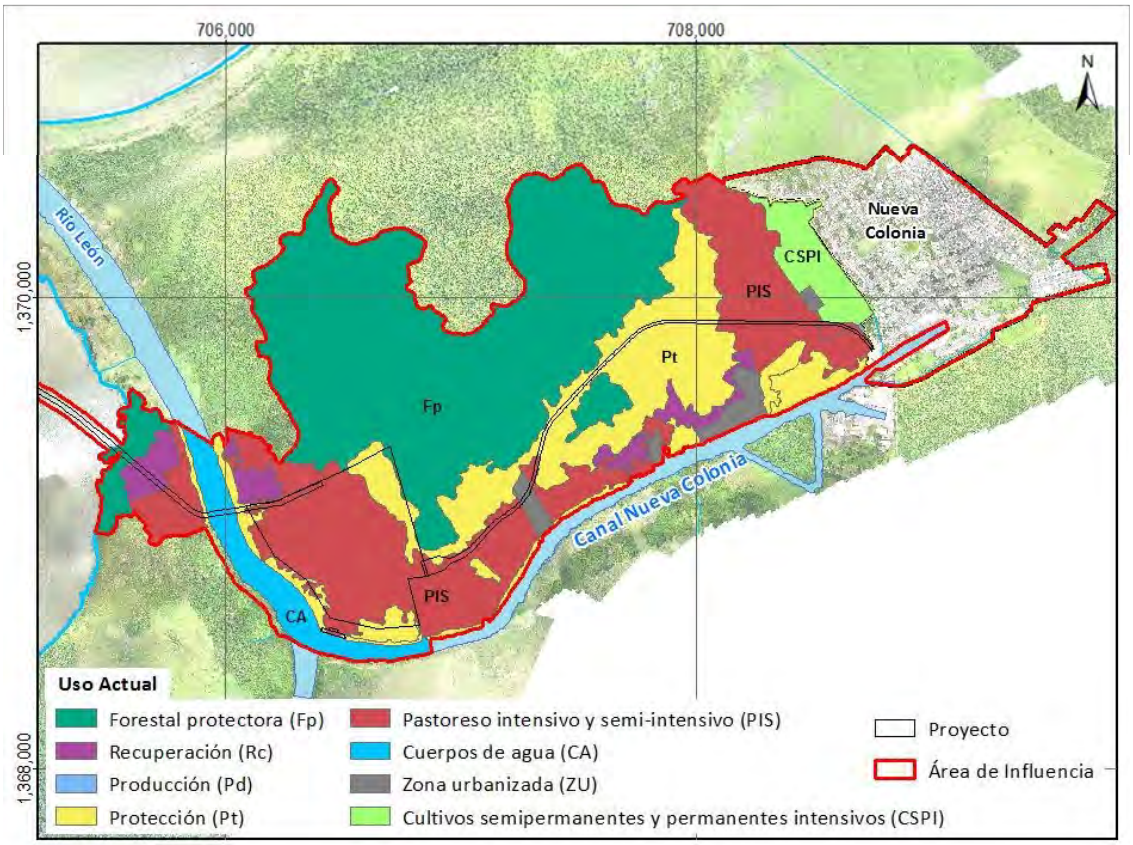
Production (Pd) Urban area (ZU)

[35] COLOMBIA. MUNICIPALITY OF TURBO. *Plan de Ordenamiento Territorial: Libro diagnóstico integrado* (Land Use Plan: Holistic Diagnostic Handbook) Turbo: 2000. Book 2. Part 2. 90 p.

[36] Ibid.

Protection (Pt) Intensive permanent and semi-permanent cultivation (CSPI)

Figure 5.26 and Table 5.11. Further details can be found in the map entitled MOD_LA_PTO_ANT_16_UsoActual.



Current Use

Protective forest (Fp) Intensive and semi-intensive grazing (Ps) Project

Restoration (Rc) Bodies of water (CA) Area of influence

Production (Pd) Urban area (ZU)

Protection (Pt) Intensive permanent and semi-permanent cultivation (CSPI)

Figure 5.26 Current land use within the project's area of influence.
Source: *Aqua & Terra Consultores Asociados S.A.S* (2015)

Table 5.11 Current land use within the project's area of influence

Current use	Current use type	Key	Area (Ha.)
Agriculture	Intensive permanent and semi-permanent cultivation	CSPI	11.2
Livestock	Intensive and semi-intensive grazing	PIS	93.1
Forestry	Production	Pd	0.04
	Protection	Pt	70.1
Conservation	Protective forest	Fp	176.6
	Water resources	Rh	152.4
	Restoration	Rc	14.9
Industrial	Industrial or commercial areas	Zic	4.5
Residential	Settlement	As	2.0
	Population center	Cp	74.7

Source: *Aqua & Terra Consultores Asociados S.A.S* (2015)

- Intensive permanent and semi-permanent cultivation (CSPI)

Intensive permanent and semi-permanent cultivation comprises crop types whose productive lifecycle lasts for between one or two years. Within the project's area of influence this use type occupies an area of 11.2 hectares, corresponding to the plots which border the population center of Nueva Colonia.

In this location, banana, plantain and some fruit crops for the domestic use of each farm were found (see Photo 5.20).

Photo 5.20 Intensive permanent and semi-permanent cultivation within the project's area of influence.

Source: *Aqua & Terra Consultores Asociados S.A.S* (2015)

- Intensive and semi-intensive grazing (PIS)

This land use comprises those areas which are primarily made up of clean or wooded grassland, where management practices hinder the presence or development of other types of cover. Within the project's area of influence this use type covers an area of 93.1 hectares, located throughout said area. The plot of land where the land terminal is intended to be built is mainly covered by natural grassland.

These areas are largely dedicated to semi-intensive livestock farming on natural and introduced grassland; the predominant grass species found there are para grass *(Brachiaria arrecta,* used primarily for raising buffalo*)* and satintail grass (*Imperata*, used for traditional livestock farming). These grasses adapt to waterlogged areas such as the flood plains that make up the area of study, which contain waterlogged soils with water saturation problems. Some aquatic plants grow in these areas, such as the common water hyacinth, *arracacho (*Montricardia arborescens*)* and the lotus. (Photo 5.21).

Photo 5.21 Clean grassland dedicated to livestock farming in the project's area of influence
Source: *Aqua & Terra Consultores Asociados S.A.S* (2015)

- Production (Pd)

This land use type consists of a teak *(tectona grandis)* forest plantation for timber production at the rotation age (approximately 12 years). During the fieldwork phase this crop was identified to be at the felling stage. For this reason it only represents a small part (400 m²) of the area of study, located adjacent to the population center of Nueva Colonia and to the banana and plantain crops, as can be seen in Photo. 5.22.

Photo. 5.22 Forest plantation of *Tectona grandis*
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015)

- Protection (Pt)

This land use type occupies an area of 70.1 hectares within the project's area of influence, dedicated to the permanent protection of water and soil resources. These pertain to the riparian forest cover located on the banks of the León River, the Nueva Colonia canal (see Photo 5.23) and the flood-prone or dryland pastures found throughout the area of influence.

Photo 5.23 Riparian forest within the project's area of influence
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015

- **Protective Forest** (Fp)

This type of land use covers an area of 176.6 hectares, corresponding to forest cover **which acts as a refuge** for the region's flora and fauna due to its level of ecological **conservation. Example**s in the area of study include mangrove and palm grove cover (Photo 5.24).

Photo 5.24 Palm grove dedicated to the protective forest use type
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015)

- Restoration (Rc)

The type of use pertains to those areas whose primary vegetation has been altered or destroyed. Examples include the mangrove areas which have been altered and, by means of successional processes, a process of restoration corresponding to the mangrove's high secondary vegetation has begun. The same occurs with those areas that show a greater degree of natural regeneration, such as areas of shrub cover that are in the process of recovering their original state of riparian forests. The areas in a state of restoration are distributed across an area of 14.9 hectares and are primarily located along the banks of bodies of water. It should be mentioned that despite being in a process of natural restoration, the human intervention experienced by these areas creates a great deal of pressure and hinders the development of the restoration process.

Photo 5.25 High secondary vegetation cover within the area of study
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015)

- Industrial or commercial areas (Zic)

This type of use relates to those areas with artificial infrastructure that are used for commercial or industrial activities within the area of study. These constructions belong to the Banacol company and are located on the right-hand bank of the Nueva Colonia canal, occupying an area of 4.5 hectares across two pieces of land. One is dedicated to a storage center for the shipping of bananas and a fuel station operates on the other.

Photo No. 5.26 The Banacol company jetty area along the Nueva Colonia canal
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- Settlement (As)

This type of use pertains to the settlement of the El Canal village, located 2km away from the town center of Nueva Colonia in the municipality of Turbo. It is accessed via an unpaved road or waterway and occupies an area of 2 hectares. This community is situated in a vulnerable area due to the increased traffic of heavy vehicles heading to the port's land terminal site. The settlement is in the process of being relocated to the population center of Nueva Colonia.

- Population center (Cp)

This type of use corresponds to the plot of land where housing is being built for the future relocation of the community belonging to the settlement of the El Canal village and to the population center of the town of Nueva Colonia in the municipality of Turbo. According to the figures recorded in the 2005 DANE census[37], the community has a population of 17,472 inhabitants and occupies an area of 74.7 hectares.

- *Conflicts due to land use*

Conflicts due to land use stem from the discrepancy between the way in which humans are currently using the land and the way in which it should be used, in accordance with its potential, purpose and environmental restrictions[38].

[37]DANE. *Boletín Censo General 2005* (2005 General Census Bulletin), Profile of Turbo, Antioquia
[38] AGUSTIN CODAZZI INSTITUTE (IGAC), COLOMBIAN CORPORATION OF AGRICULTURAL RESEARCH (CORPOICA). *Zonificación de los conflictos de uso de las tierras del país. Capítulo IV Uso Adecuado y Conflicto de Uso de las Tierras en*

According to the land use zoning included in the Land Use Plan (LUP) for the municipality of Turbo[39], the project's area of influence falls within the industrial development, port and service zone, with a small part of the area of study in the category of conservation and ecosystem restoration. The latter category refers to the protective forest reserve of the wetlands of the Suriquí and León rivers, as shown in Figure 5.27. Given that the aim of the project is the construction and operation of a major maritime port, it is in accordance and consistent with the uses that are established and permitted in the land use zoning determined by the LUP[40] for the municipality of Turbo. The land is considered to be without conflicts of use or in adequate use. (A).

Colombia (Zoning of the use conflicts on the country's land. Chapter IV Appropriate Use and Use Conflicts of Land in Colombia. Bogotá, D.C 2002. 106 p.

[39] COLOMBIA. MUNICIPALITY OF TURBO, 2000. Op. Cit.

[40] COLOMBIA. MUNICIPALITY OF TURBO, 2000. Op. Cit. 90 p.

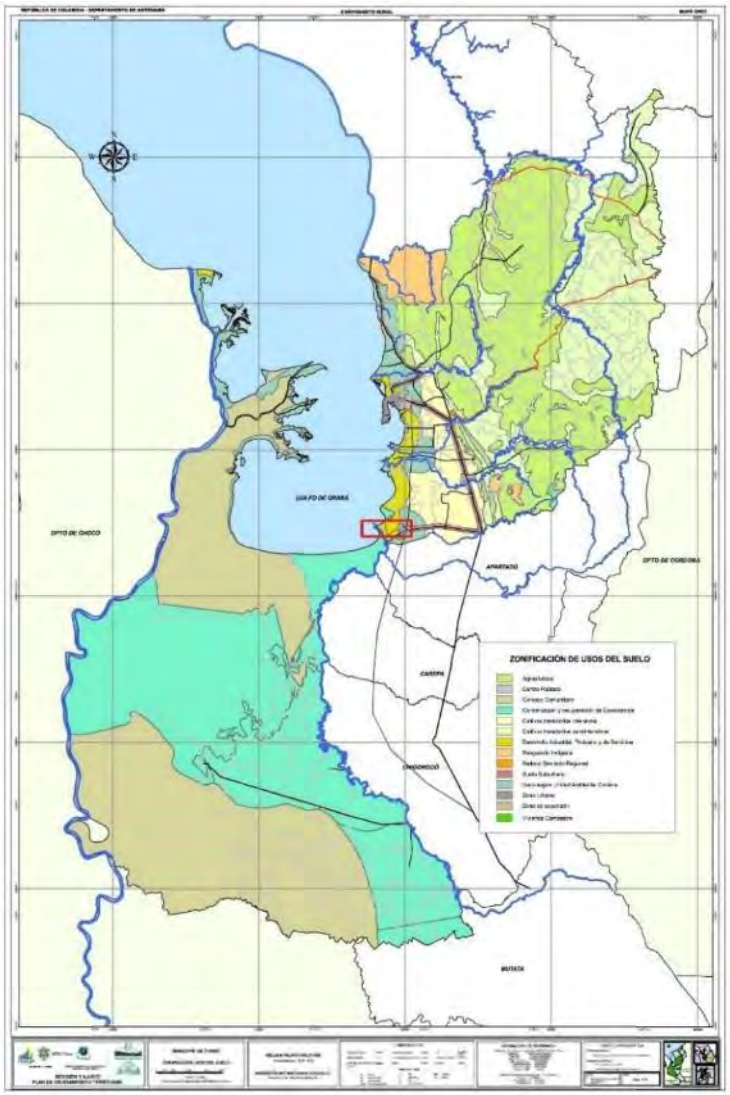


Figure 5.27 Land use zoning of the municipality of Turbo
Source: LUP for the municipality of Turbo, 2000[41]

Once analysis is carried out of the current use and recommended potential use of the land within the project's area of influence, conflicts stemming from land use are then considered.

Within the project's area of influence, 76.7% (Table 5.12) of the land is **without conflicts of use** or **in adequate use (A).** It is classified as such because the

[41] Ibid.

dominant environmental endowment in the area is coherent with the population's demand for natural resources.

Likewise, conflicts due to **slight underuse (S1)** were identified, which correspond to 6.1% of the area of study. This refers to those areas which are currently used for intensive and semi-intensive grazing despite being land with the potential for semi-intensive permanent and semi-permanent cultivation. An area of teak (*Tectona grandis*) plantation was also identified, which is equivalent to 400 m^2 and at the felling stage. According to land use capacity it should be used for semi-intensive permanent and semi-permanent agricultural cultivation, for which reason it is deemed to be in **severe underuse (S3).**

Within the piece of land where the land terminal is intended to be built, a conflict due to **severe overuse (O3)** was found which corresponds to 0.5% of the project's area of influence. This stems from the cover of the area being clean grassland and the land use purpose being protective forest, due to the moisture of the soil. It should be clarified that the existing grasses on this piece of land and in the surrounding area are of natural origin, grow in floodplain landscapes and adapt very well to soils with problems of waterlogging. Likewise, there is minimal presence of livestock and pressure on soil resources is of little relevance (Use Conflict

A- No conflicts	S1- Slight underuse	Project
O2- Moderate overuse	S3- Severe underuse	Area of Influence
O3- Severe overuse	ZU- Urban Area	

Figure 5.28).

Besides that, areas categorized as Urban Areas (ZU) were identified, which are related to current and potential use given that they are areas containing settlements, population centers and industrial and commercial zones.

The types of conflicts identified within the project's area of influence are listed in Table 5.12, along with their area in hectares and as a percentage. **Use Conflict**

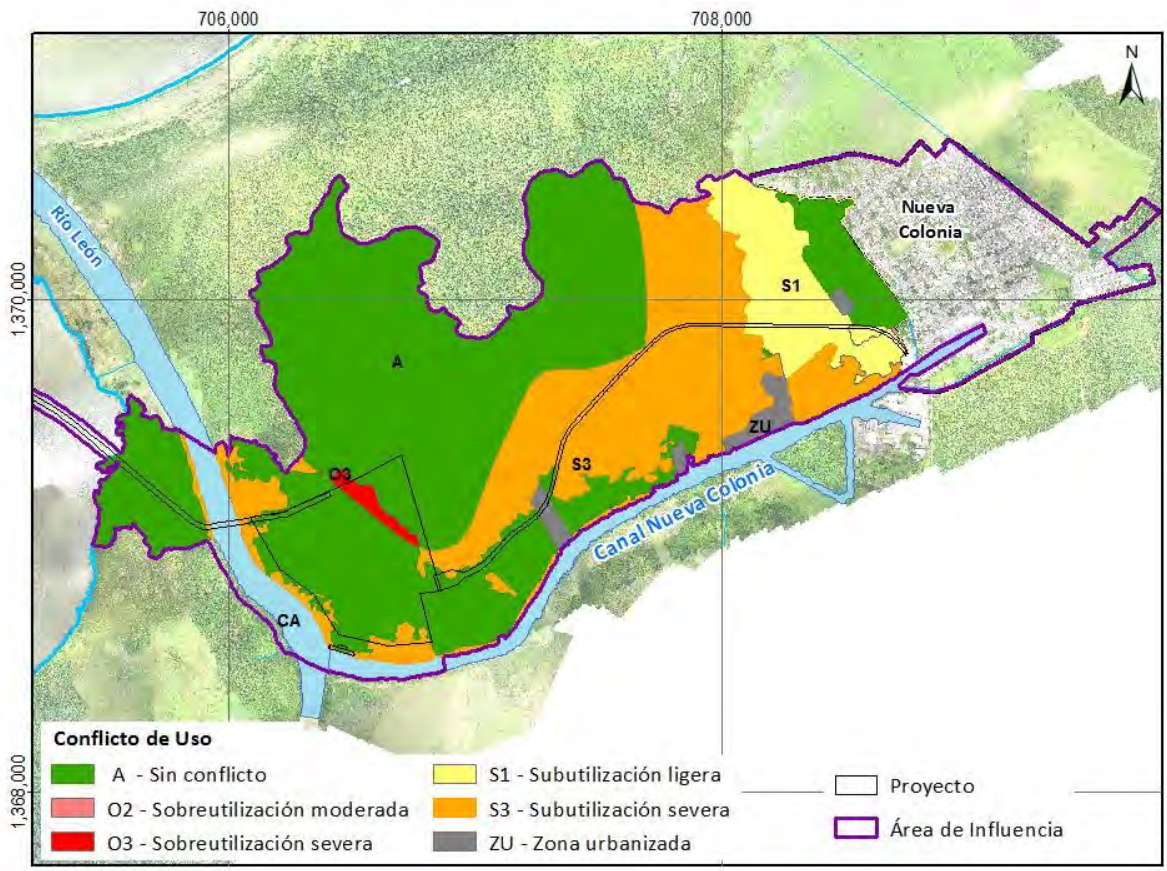
B- No conflicts	S1- Slight underuse	Project
O2- Moderate overuse	S3- Severe underuse	Area of Influence
O3- Severe overuse	ZU- Urban Area	

Figure 5.28 shows the spatial distribution of each of these categories (see map entitled MOD_LA_PTO_ANT_17_ConflictoUso).

Table 5.12 Conflicts due to land use identified within the project's area of influence

Type of conflict	Symbol	Area (Ha.)	Area (%)
Land without conflict or in adequate use	A	352.2	76.7%
Conflict due to slight underuse	S1	28.0	6.1%
Conflict due to severe underuse	S3	0.0	0.0%
Conflict due to severe overuse	O3	2.5	0.5%
Urban Area	ZU	76.7	16.7%

Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015)



Use Conflict

C- No conflicts	S1- Slight underuse	Project
O2- Moderate overuse	S3- Severe underuse	Area of Influence
O3- Severe overuse	ZU- Urban Area	

Figure 5.28 Conflicts due to land use within the project's area of influence
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015)

5.1.5 Hydrology

Hydrological characterization is carried out for the project's area of influence with the aim of characterizing the area in terms of the availability of surface water resources. To that end, the lentic and lotic ecosystems present in the area of influence were identified.

- *Lentic and lotic systems*

- Lentic systems

The lentic systems in the area of influence were identified in two stages. The first took place over the satellite image in order to carry out a prior identification of systems of this type. The second stage involved fieldwork or visits to the project area, for the purpose of corroborating the initial cartographic data. Once these two stages had been completed, no natural lentic systems associated with coastal lagoons or intertidal marshes were found. Likewise, no artificial lentic systems associated with ponds or reservoirs were found.

- Lotic systems

Regionally, the lotic systems present in the area are shown in

Key

Vehicular routes

Drainage

Farm

Figure 5.29. The project is located on the east bank of the León River, approximately 2.3km away from its estuary in Bahía Colombia in the southern region of the Gulf of Urabá.

Key

Vehicular routes

Drainage

Farm

Figure 5.29 Diagram of the rivers that flow into the Gulf of Urabá
Source: *ARAÚJO IBARRA & ASOCIADOS S.A. (*2009)[42].

[42]ARAÚJO IBARRA & ASOCIADOS S.A. *Estudio de factibilidad para el puerto de Bahía Colombia (*Feasibility study for the Bahia Colombia port*)*. April 23rd, 2009.

The Gulf of Urabá receives a high water supply, which is directly responsible for the sedimentation processes that occur in the catchment area. Its tributaries make up a complex river system, consisting primarily of 10 rivers which empty their waters at different points in the Gulf[43] (Table 5.13).

Table 5.13 River system of the Gulf of Urabá: flow and area of the rivers' catchment areas

River	Average flow (m³/s)	Catchment area (km²)
Atrato	4,750.00	35,700
León	40.00	2,250
Suriquí	20.00	71
Turbo	5.50	95
Caimán Viejo	4.00	97
Caimán Nuevo	3.70	85
Bobal	3.50	59
Necoclí	3.50	0
Guadualito	2.30	0
Currulao	2.10	0

Source: SENER. Feasibility study for the development of the port system in Urabá (2007).

The lotic systems of interest identified for the area related to the project are the León River (as a natural lotic system) and the Nueva Colonia canal (as an artificial lotic system). The location of the hydrographic network that exists in the area of influence can be seen in the map entitled MOD_LA_PTO_ANT_18_Hidrología. Both systems and their main characteristics are described below.

❖ León River

The León River has an approximate catchment area of 2,250km², which goes from its source in the south-western foothills of the Abibe mountains to the north of the municipality of Mutatá, to its mouth 83km further downstream in Bahía Colombia. The rivers Carepa, Apartadó, Chigorodó, Zungo, Vijagual and Grande feed into it, and nearly all these tributaries are characterized by the presence of very similar altitudinal segmentation, manifesting itself in their headwaters as mountain streams with torrential systems and potential instability in their canyons. They cross areas of plains and hills, shaping narrow alluvial valleys in the foothills of the mountains, until they reach the alluvial plain of the León River; here, they divide up into many branches, making up a highly complex network[44].

[43] SENER. *Estudio de viabilidad del desarrollo del sistema portuario en Urabá* (Feasibility study for the development of the port system in Urabá (Colombia). 2007.

[44] COLOMBIA. MUNICIPALITY OF TURBO. *Plan de Ordenamiento Territorial: diagnóstico físico-ambiental (*Land Use Plan: physical and environmental diagnosis). Turbo, 2000. Book 1. Part 1. Page 31.

Its main course takes the form of an arch that curves across the alluvial plain. Here, it breaks down into networks of very complex channels which are favorable for hydrophilic resources that flow through a large part of the Turbo territory, over flood plain and marine coastal complex units[45].

The water flow distribution of the León River with its tributaries is bimodal. In the rainiest months of rainiest months of September and October episodes of overflowing are recorded with average flow with average flow rates of over 100 m³/s, exceeding for several days the capacity of the cross-cutting the cross-cutting sections, which is between 180 and 200 m³/s in the alluvial section of the of the Barranquillita station. During the period of least rain, between the months of January and January and March, flow rates are below 30 m³/s with a monthly minimum of 16 m³/s in March (see in March (see

Flow (m³/s) January March May July September November

Figure 5.30)[46].

Water yield during the first months of the year is in the order of 20 l/s/km², in comparison with figures exceeding 120 l/s/km² in the wettest period. During the latter period, this is due to the establishment of hydrological continuity in the wetland systems of the Lower Atrato River and the León River, thus increasing surface runoff in the catchment area[47].

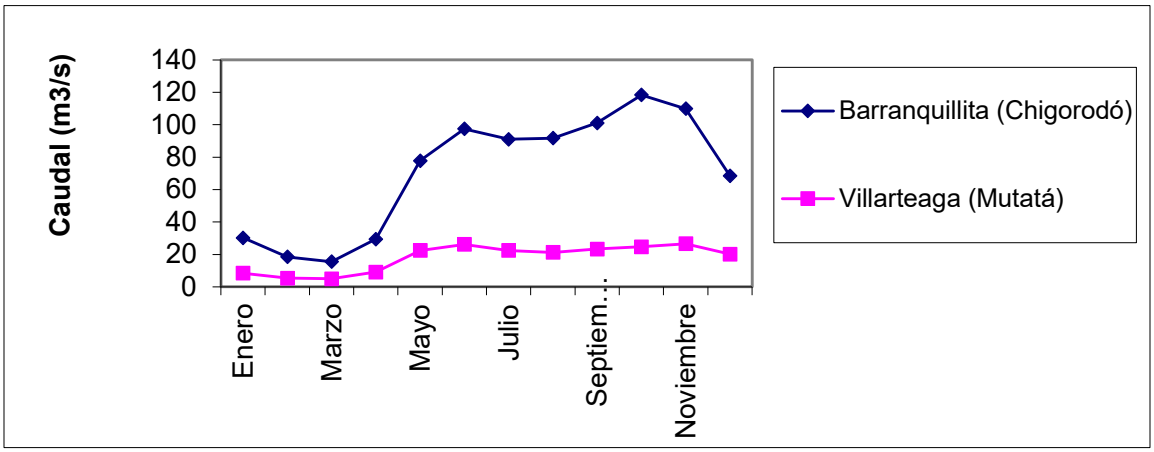
The average annual flow of the Villarteaga River (upper part of the León River) is 18 m³/s, while in m³/s, while in Barranquillita it stands at 70.8 m³/s. This means that the average water yield for the yield for the catchment area varies between 135 and 93 l/s/km², figures which are considered to be considered to be high (see

Flow (m³/s) January March May July September November

Figure 5.30 and J F M A M J J A S O N D

Figure 5.31)[48].

[45] Ibid. Book 1, Comp. 2 (Biotic). Page 21.
[46] Ibid.
[47] Ibid.
[48] Ibid.



Flow (m³/s) January March May July September November

Figure 5.30 Average monthly flow of the León River at the Barranquillita and Villarteaga stations

Source: LUP Turbo, 2000[49].

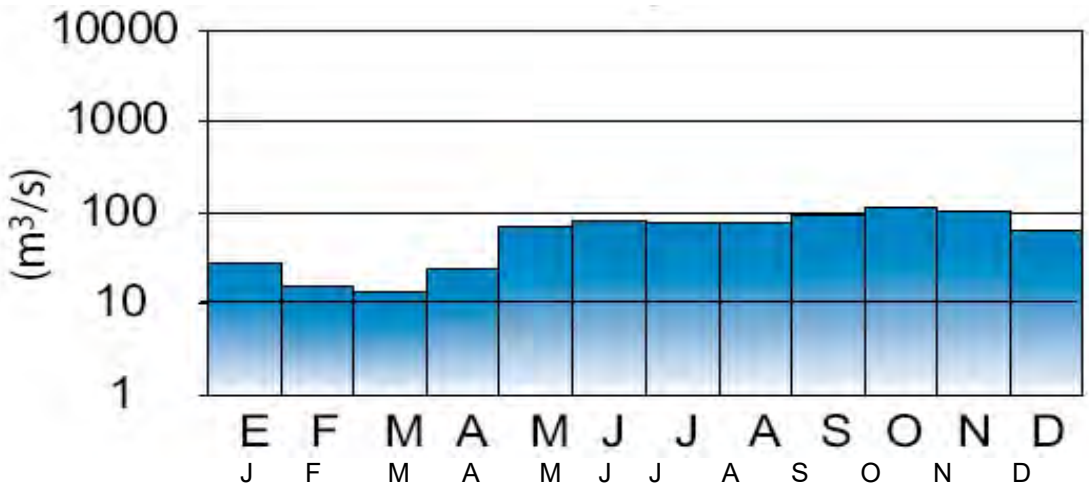


Figure 5.31 Average monthly flow of the León River at the Barranquillita station (statistics 1989-1993)

Source: INVEMAR and Antioquia Departmental Government. Atlas of the Gulf of Urabá (2007)[50]

The 1995 INAT study regarding minimum or drought flows estimates that at the point of the Barranquillita station the León River dries up completely once every 67 years,

[49] COLOMBIA. MUNICIPALITY OF TURBO. Land Use Plan, 2000. Op. Cit.

[50] José Benito de Andreis Institute for Marine and Coastal Research (INVEMAR) and the Antioquia Departmental Government. *Atlas del golfo de Urabá: una mirada al Caribe de Antioquia y Chocó. Series de publicaciones especiales n° 12* (Atlas of the Gulf of Urabá: A glance at the Antioquia and Chocó Caribbean). Santa Marta: 2007. 180 pages. ISBN 978-958-98104-3-9

whereas the average minimum which occurs with a return period of one year is around 13.9 m³/s.

The average multiannual flow of the León River is 70 m^3/s, a figure calculated at Barranquillita (IDEAM); as this station is located upstream from the river's estuary, it does not consider the discharge of tributaries such as the Carepa, Chigorodó, Apartadó and Zungo. Calculations for average daily flow rates estimated by Roldán (2008) are detailed below.

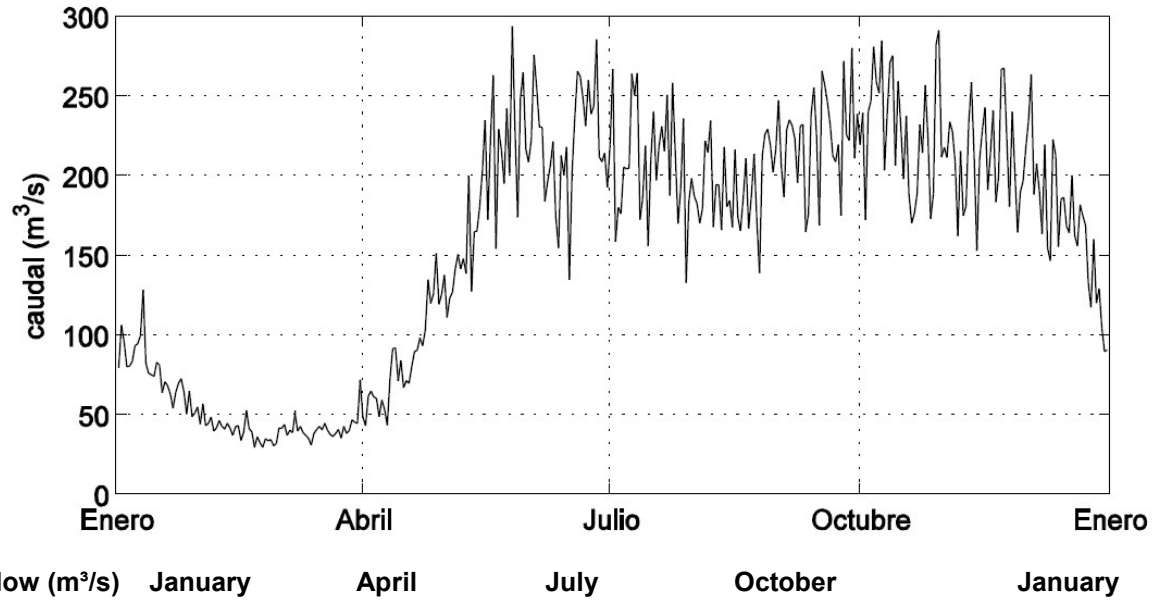


Figure 5.32 Annual cycle of daily flow rates of the León River
Source: ROLDAN, 2008

Taking the project's characteristics into account, whereby the León River will be used for the collection of surface water and the disposal of waste water, and given the absence of direct intervention on its banks, the watercourse is not expected to show any deterioration in its natural conditions with regards to seasonality and areas of flooding.

- **Nueva Colonia Canal**

The Nueva Colonia canal was constructed in 1974 by the Maderas Del Darién timber company for the purpose of transporting the material resulting from their activities. Over the course of time if has been used by a variety of companies for the transportation of timber and fruit (bananas for exportation). Frutera de Sevilla was

the first banana company to operate on the canal and it is currently used by companies such as Banacol and Uniban to ship the fruit.

The operation of the Nueva Colonia canal's main source of water recharge is dependent on the flow of water from the León River. The canal is approximately 31km long, with a width that varies from a minimum of 30m to a maximum of 90m at the estuary of the León River (

Nueva Colonia Canal

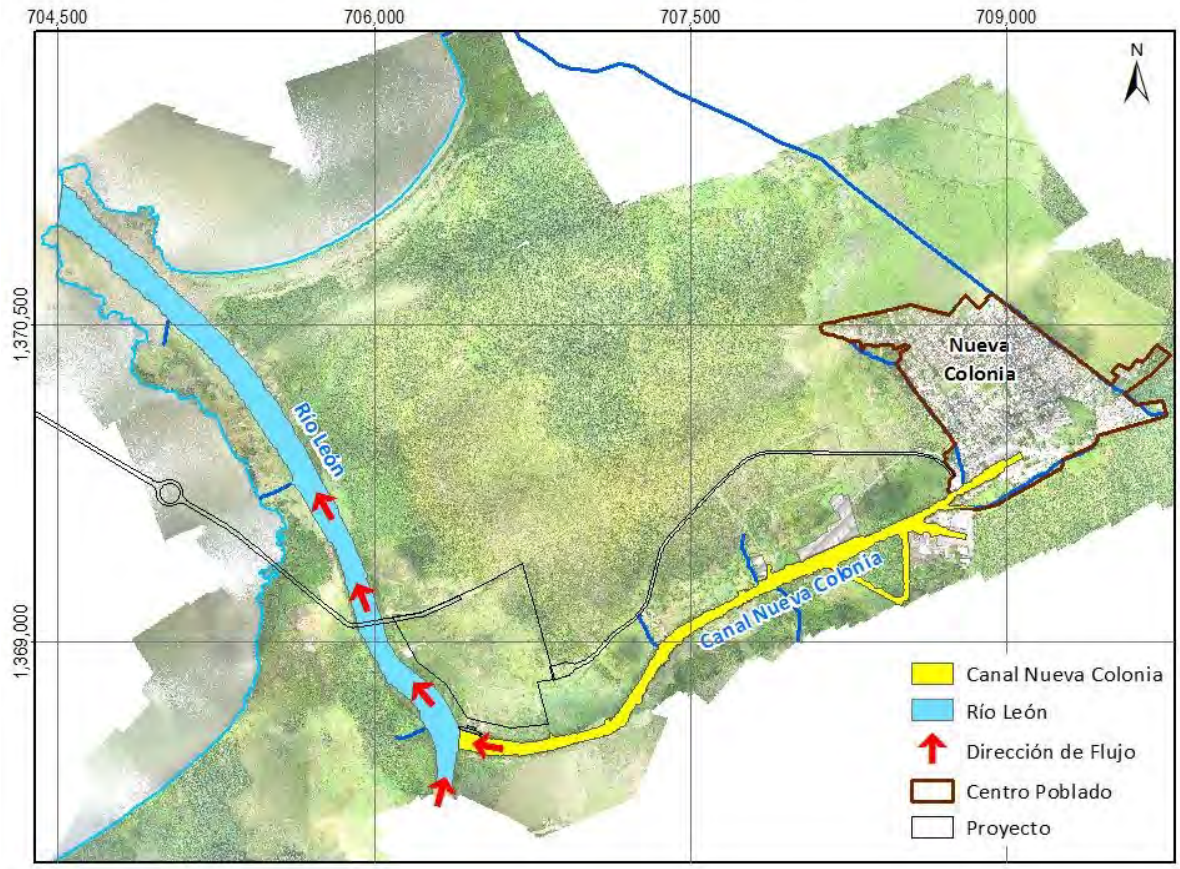
León River

Flow Direction

Population Center

Project

Figure 5.33).



Nueva Colonia Canal

León River

Flow Direction

Population Center

Project

Figure 5.33 Nueva Colonia canal
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S.* (2015)

- *Marine and coastal systems*

The coastal marine ecosystems present in the project's area of influence are shown on the map entitled MOD_LA_PTO_ANT_33_Ecosistema.

- *Water basins*

As previously mentioned, the Gulf of Urabá is made up of various rivers, among which the main ones are the River Atrato, León River, River Suriquí and the River Turbo.

As can be observed in Table 5.13 the River Atrato is the main tributary of the Gulf of Urabá catchment area. Situated on the western edge of the Gulf, it is 670km long with a drainage basin of approximately 35,700 km². The average annual volume of water that enters the Gulf from the Atrato is roughly 4,500 m³/s.

The second most important river due to its volume and navigability is the León River, followed by the Suriquí and, with the lowest volumes, the Rivers Turbo, Caimán, Bobal, Necoclí, Guadalito and Currulao.

During the period of least rain the flow rate of the rivers decreases and the presence of berms means that they do not drain easily. The mouths of some rivers can even be obstructed, potentially rendering their contribution non-existent.

The volume of precipitation received by the basins of the rivers that empty into the Gulf of Urabá is determined by the weather. This has a direct influence on the rivers' volumes and on the amount of terrigenous material deposited in the Gulf of Urabá and Bahía Colombia.

Due to the location and characteristics of the project only one river basin is associated with its area of influence, being that of the León River. The location and distribution of said basin can be seen on the map entitled MOD_LA_PTO_ANT_18_Hidrologia.

- *Wetland, Marsh and Mangrove Complexes*

No wetlands or marshes are found in the project's area of influence and direct areas of intervention. However, it should be pointed out that during the rainy season flooded areas can appear.

At a regional level a Protective Wetland Reserve has been declared between the Rivers León and Suriquí, located in the Gulf of Urabá in the north-west of the Antioquia department. In terms of mangroves, the high dense mangrove ecosystem of Halobioma Del Caribe has been identified, which occupies 6.98 hectares of the area of influence. (See section 5.2).

- *Areas of flooding*

The results of geomorphological characterization show that the project's area of influence is framed by the alluvial floodplains of the León River. The topography of the surface is flat, very low-lying and poorly drained. It is also affected by daily tidal fluctuations with a local relief of no more than one meter, the result of the recent accumulation of sediment that has been transported by the water sources that run along the western flank of the Abibe mountains.

The aforementioned characteristics make this area susceptible to flooding due to a swelling of the León River, which could increase the chance of flooding when combined with a high tide. In the project's case this is considered to be a medium-level threat, as the piece of land where the facilities will be built is separated from the León River by a high dyke which protects it from potential flooding. The areas adjacent to the coast and the natural and artificial drainages have been designated as at high risk of flooding. (See section 5.1.2).

Furthermore, according to analysis presented in the early warning information system of the area's vulnerability and susceptibility to climate change (Figure 5.34-Tremarctos)[51], the Urabá region is situated in an area that is susceptible to flooding.

[51] RODRÍGUEZ-MAHECHA, J.V., ARJONA-HINCAPIÉ, F., MUTO, T., URBINA-CARDONA, J.N., BEJARANO-MORA, P., RUIZ-AGUDELO, C., DÍAZ GRANADOS, M.C., PALACIOS, E., MORENO, M.I., GÓMEZ, A. and GEOTHINKING LTDA. 2015. Ara Colombia. *Sistema de Información Geográfica para el Análisis de la Gestión Institucional Estatal (Módulo OtusColombia) y la Afectación a la Biodiversidad Sensible y al Patrimonio Cultural (Módulo Tremarctos-Colombia)* Geographical Information System for analysis of state institutional management (OtusColombia Module) and of the effects on sensitive biodiversity and cultural heritage (Tremarctos-Colombia Module). Version 2.0 (28; 01; 2013) Conservation International-Colombia and the Environment and Sustainable Development Ministry. Information system available online at http://www.tremarctoscolombia.org/ [Accessed October 13th, 2015].

Figure 5.34. Areas susceptible to flooding in the Gulf of Urabá
Source: Tremarctos[52]

- *Changes in salinity and the penetration distance of the salt wedge*

The salt wedge is defined as the body of salt water of great length with a wedge-shaped cross-section, which enters inland either permanently or temporarily and displaces the fresh water. The fresh water is found in the surface layer and forms a narrow layer, and mixing is restricted to a narrow transition layer between the fresh water (surface) and the salt wedge of the bed. The National Hydrological Plan (PHN)[53] points out that the geometry of the salt wedge depends on the morphology of the riverbed, on the circulating flow and on the sea level.

[52] Cit. Op.
[53] NATIONAL HYDROLOGICAL PLAN (NHP) 2000. Environmental analysis. Madrid, September 2009. 266 p.

The presence of a salt wedge can have a variety of environmental consequences. Among other adverse effects, in eutrophic waters with an excess of algae it can lead to anoxia (oxygen depletion) of the sea bed, causing animals to suffocate and limiting the lifespan of bacteria and some organisms that are highly resistant to a lack of oxygen (Ibáñez et al., 1999[54]). On the other hand, in non-eutrophic waters the presence of a salt wedge represents a natural phenomenon that should not be expected to cause damage to adjacent agricultural land due to salinization. Furthermore, salt wedges can affect coastal aquifers and leave their water unsuitable for human consumption.

As part of the study performed by Álvarez[55], three (3) campaigns were carried out to measure various oceanographic variables, including salinity profiles in the delta of the León River (Figure 5.35 and Figure 5.36).

[54] IBAÑEZ, C.N., PRAT A., CANICIO A., CURCÓ. 1999. *El delta del Ebro, un sistema amenazado* (The Ebro Delta, a system under threat). Coagret. Bakeaz, Bilbao. 1999

[55] ÁLVAREZ SILVA, O. A. 2011. *Modelación morfodinámica de desembocaduras a escala intra-anual* (Morphodynamic modelling of estuaries at an intra-annual scale). Thesis presented as a partial requirement to obtain the title of Master in Water Resource Engineering. National University of Colombia, Mining Faculty, School of Geosciences and the Environment. Medellín, Colombia. 135p.

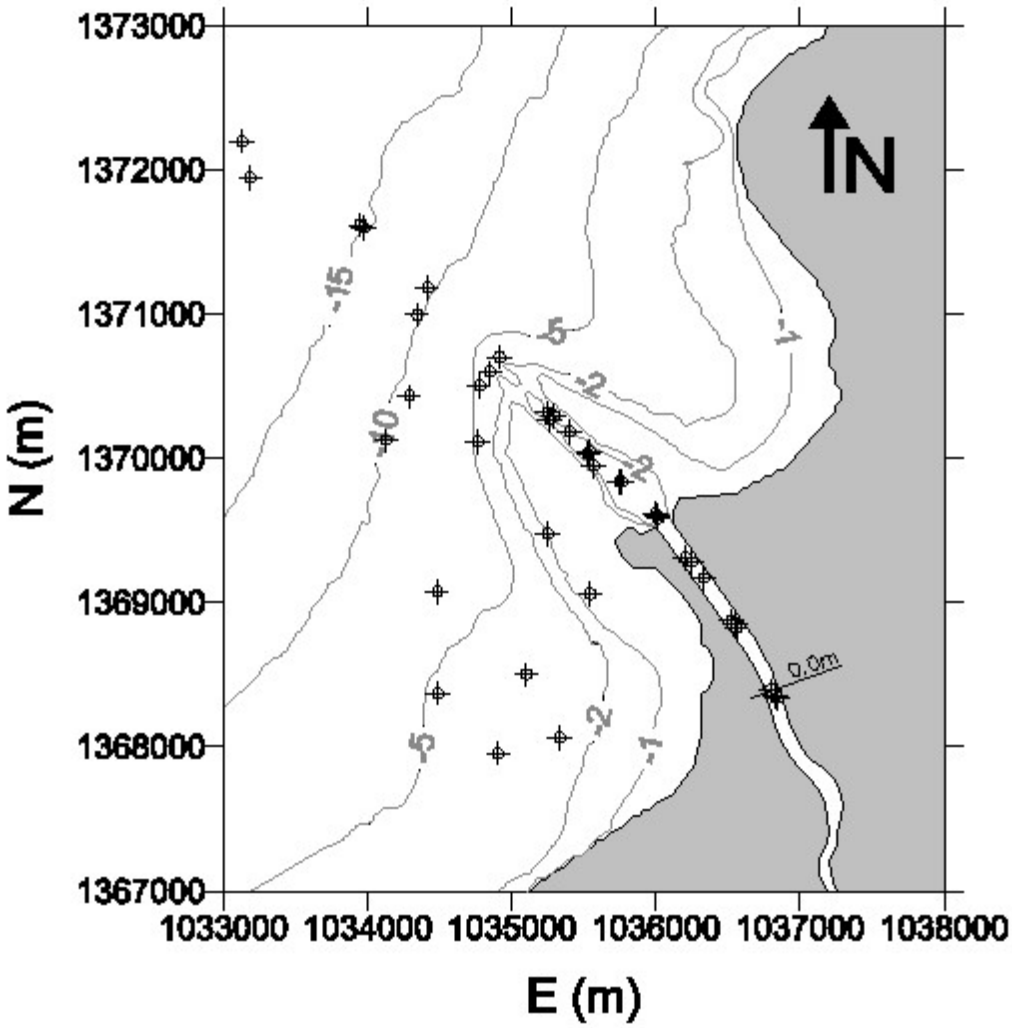


Figure 5.35. Spatial distribution of the profiles measured in the delta of the León River
Source: Álvarez, 2011

The results of these studies with regards to the influence of the salt wedge are presented overleaf.

- During the first study (carried out in the dry season), the halocline was found at an estimated depth of 10m. In addition, a steep vertical gradient of salinity was present, ranging from salinity below 5 to figures reaching 35 in less than one meter of depth.
- In the second study (corresponding to the wet season), the halocline was found at shallower depths (between 0-5m) and the salinity values on the surface ranged between 15 and 20. These measurements also determined that the salt wedge extends as far as the prodelta of the estuary but does not reach the river.
- The third study showed values and salinity patterns similar to those found during the first campaign.

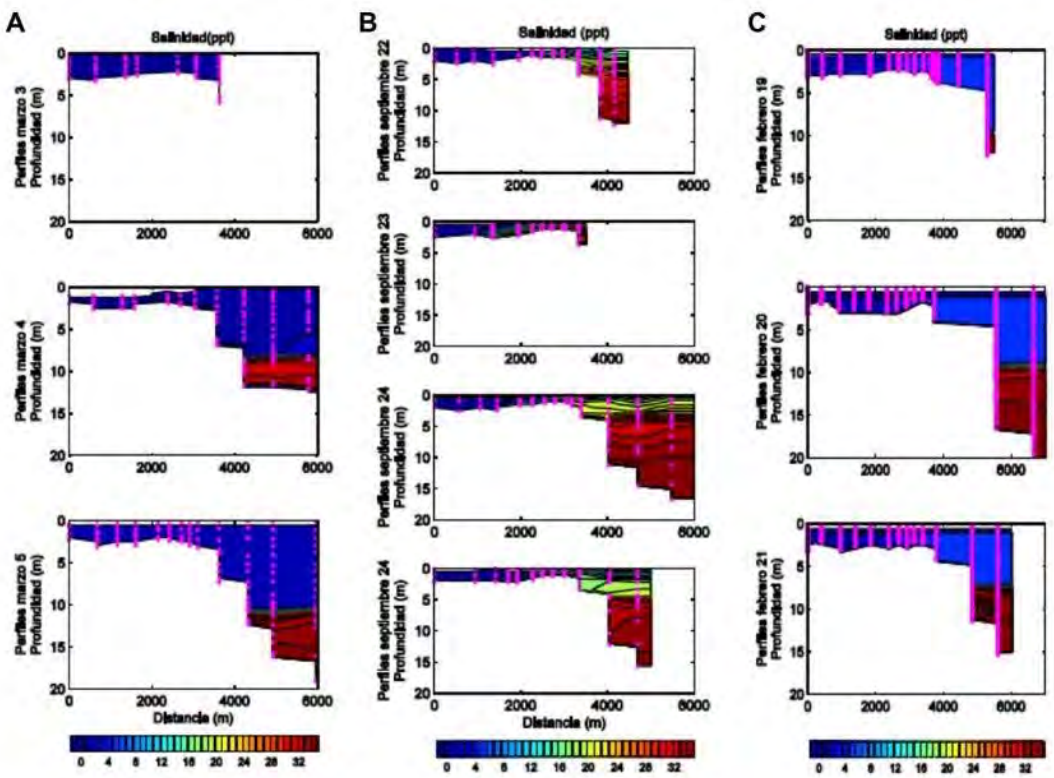


Figure 5.36. Salinity measurements in the delta of the León River. A: dry season. B: wet season. C: dry season.
Source: Alvarez, 2011

5.1.6 Water Quality

Stations A1 and A2 are positioned along the León River; A1 is located downstream from the outlet of the Nueva Colonia canal into the León River, and A2 sits downstream from the bridge that will be built over the León River, which forms part of the viaduct connecting the land terminal and the water terminal.

- Stations monitoring water quality and inland sediment

Table 5.14 shows the MAGNA-SIRGAS planar coordinates (origin Bogotá) for the sampling stations established for analyzing water quality and inland sediment in the project's area of study. The location of the stations is shown in Figure 5.37 and can be seen in greater detail on the map entitled MOD_LA_PTO_ANT_19_AguaSedimento.

Table 5.14 Location of water quality and inland sediment monitoring stations

ID	Station	MAGNA SIRGAS planar coordinates (Origin BOGOTÁ)	
		EAST	NORTH
A1	León River upstream station	706,327.33	1,368,671.49
A2	León River downstream station	705,956.74	1,369,095.03

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S* (2015)

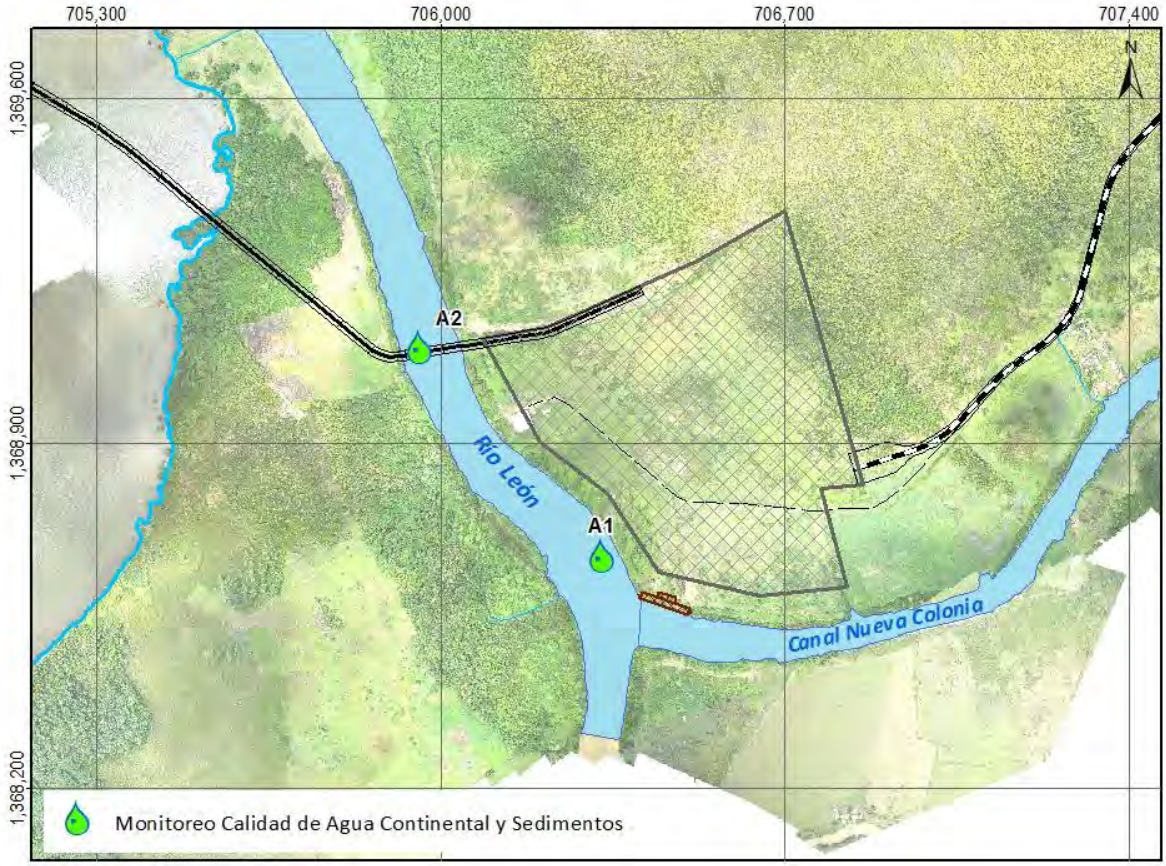


Figure 5.37 Location of water quality and inland sediment monitoring stations

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S* (2015)

- Results obtained regarding the quality of inland water

The physicochemical and bacteriological values (evaluated for the purpose of characterizing the body of water that could be affected by the development of the project) match those established in the reference terms for the production of Environmental Impact Studies (EIS) in projects to construct, extend and operate major maritime ports (M-M-INA-05)56.

56 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Resolution 0112 (January 28th, 2015). *Por la cual se adoptan los términos de referencia para la elaboración del Estudio de Impacto Ambiental – EIA, requerido para el trámite de la licencia ambiental de los proyecto de construcción o ampliación y operación de puertos marítimos de gran calado y se toma otras determinaciones* (Adopting the reference terms for the production of Environmental Impact Studies required for processing the environmental licenses of projects to construct or extend and operate major maritime ports). Bogotá D.C., 2015. 103 p.

The results of the values that were recorded in-situ and those evaluated in the laboratory are presented below.

❖ Results of in-situ values

Table 5.15 shows the results of the values that were recorded in-situ for the stations located along the León River.

Table 5.15 Results of the measurement of values in-situ- inland water

Sampling point	pH (units)	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity, ms/cm	Oxygen saturation (%)
A1	5.45	27.8	5.27	0.425	67.0
A2	5.69	28.0	3.23	0.283	41.2

Source: *SGS Colombia S.A.S* (July 2015)

❖ Results analyzed in-laboratory

The results of the values which were analyzed in-laboratory for the stations located along the León River can be seen in Table 5.16.

Table 5.16 Values analyzed in-laboratory- surface water

Values	Results	
	A1	A2
Acidity, mg CaCO3/L	11	15
Alkalinity, mg CaCO3/L	66	73
True color, UPC	20	24
Biochemical oxygen demand, mg O2/L	<2	191
Chemical oxygen demand, mg O2/L	<10	319
Calcium hardness ,mg CaCO3/L	44	194
Total hardness, mg CaCO3/L	115	439
Total phenols, mg phenol /L	<0.075	<0.075
Total phosphorus, mg P/L	2.24	13.4
Fats and oils, mg F&O/L	<0.8	<0.8
Total nitrogen, mg N/L	<5.16	<5.16
Total dissolved solids ,mg TDS/L	176	148
Sedimentable solids ,ml/L	2.0	0.20
Total suspended solids, mg TSS/L	743	17200
Turbidity, NTU	159	1490

Values	Results	
	A1	A2
Total Coliforms, NMP/100 ml	73800	703000
Escherichia Coli, NMP/100 ml	7400	75000
Total barium, mg Metal/L	0.243	2.85
Total cadmium, mg Metal/L	<0.002	0.002
Total copper, mg Metal/L	0.044	0.489
Total chromium, mg Metal/L	0.014	0.12
Total mercury, mg Metal/L	<0.00027	<0.00027
Total nickel, mg Metal/L	0.016	0.143
Total silver, mg Metal/L	<0.0004	<0.0004
Total lead, mg Metal/L	0.005	0.045
Total selenium, mg Metal/L	0.005	0.027
Total arsenic, mg Metal/L	<0.010	<0.010
Total zinc, mg Metal/L	0.26	1.51

Source: *SGS Colombia S.A.S* (July 2015)

- Analysis of inland water quality results

Analysis is provided below of the physicochemical and bacteriological values recorded in-situ and in-laboratory for stations A1 and A2. These stations are located along the León River downstream from its confluence with the Nueva Colonia canal, and are the closest areas to the project's construction work.

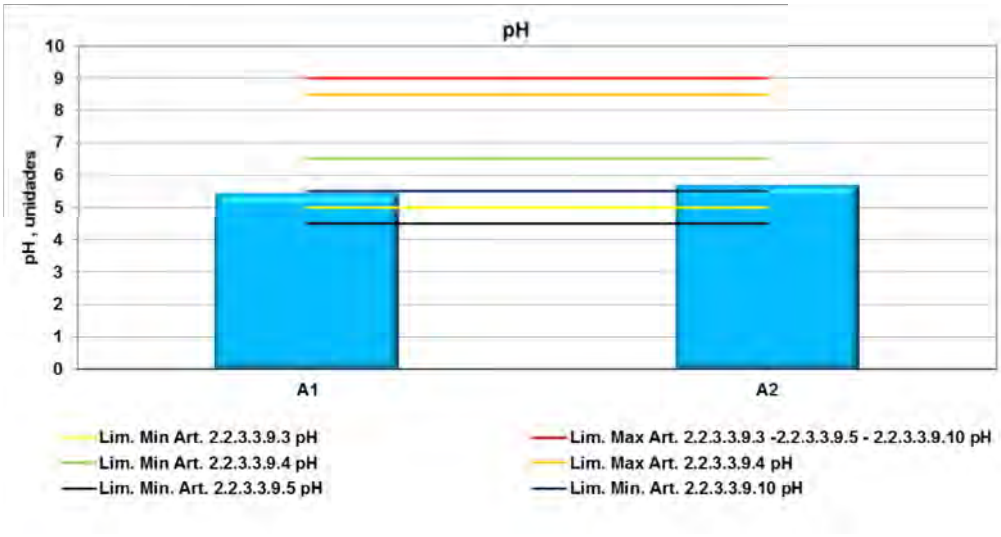
❖ Potential Hydrogen –pH units

The waters of the León River showed slightly acidic characteristics, which was determined by the pH values recorded, corresponding to 5.45 at point A1 and 5.69 at point A2. This is associated with the presence of bicarbonates, which can act as an acidic or basic substance due to their amphoteric characteristics.

With regards to compliance with Decree 1076 of 2015[57], the reported values fall within the ranges established in Articles 2.2.3.3.9.3 (Conventional treatment and quality criteria for human and domestic consumption) and 2.2.3.3.9.5 (Quality criteria for agricultural use). However, the values are outside the ranges established in Articles 2.2.3.3.9.4 (Disinfection and quality criteria for human and domestic

57 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). *(Issuing the Single Regulatory Decree of the Environment and Sustainable Development Sector).* Section 3 (*Quality criteria for the allocation of the resource).* Bogotá D.C., 2015

consumption) and 2.2.3.3.9.10 (Quality criteria for the conservation of flora and fauna). (See Figure No. 5.38).



Minimum limit- Article 2.2.3.3.9.3 Maximum limit- Article 2.2.3.3.9.3…….

Minimum limit- Article 2.2.3.3.9.4 Maximum limit- Article 2.2.3.3.9.4

Minimum limit- Article 2.2.3.3.9.5 Maximum limit- Article 2.2.3.3.9.10

Figure No. 5.38 Potential Hydrogen results– surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015) with results from SGS S.A.S (2015)

- **Temperature (ºC)**

The temperature of water is of vital importance in the development of the various processes that take place in it; an increase in temperature alters the solubility of substances, increasing dissolved solids and decreasing gases. For every increase of ten degrees the amount of biological activity approximately doubles (Q10 law), although above a certain value that is particular to each living species it has a lethal effect on organisms. An abnormal increase in water temperature that occurs for non-climatic reasons is usually caused by the disposal of water used in industrial heat exchange processes. The temperature was determined by means of thermometry carried out in-situ[58].

58 AZNA JIMENEZ, A. (Determining the physico-chemical parameters of water quality), 2000. [Online] <http://ocw.uc3m.es/ingenieria-quimica/ingenieria-ambiental/otros-recursos-1/OR-F-001.pdf> [Accessed on April 10th, 2015]

The water temperature of the León River showed a stable pattern as no major differences were seen at the monitoring points, with values of 27.8ºC and 28.0ºC recorded at stations A1 and A2 respectively, ruling out few thermal alterations that could increase water temperature. The values reported are associated with the geographical location of the monitoring points; with regards to regulatory compliance, Decree 1076 of 201559 does not establish a compliance limit for the allocation of the resource (see Figure 5.39).

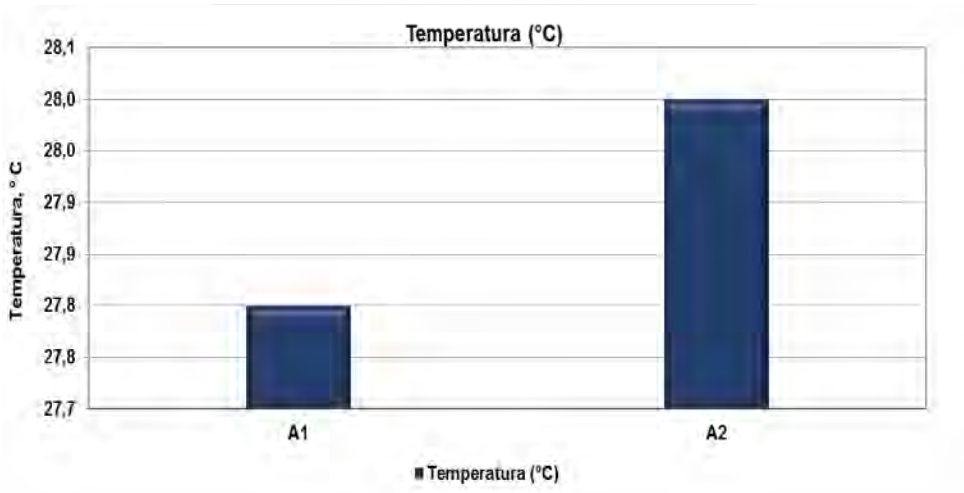


Figure 5.39 Temperature results – surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015) with results from *SGS S.A.S* (2015)

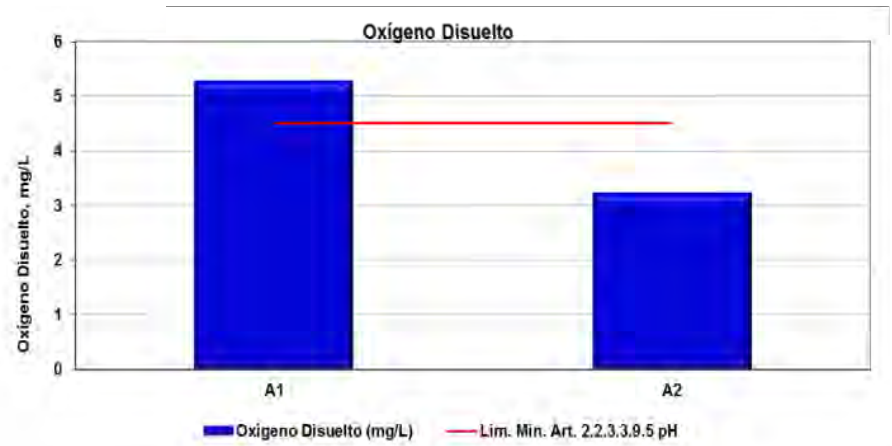
❖ Dissolved Oxygen

Dissolved oxygen is required for micro-organisms and other forms of life to breathe, and measures the capacity of water to sustain aquatic life. This variable is necessary to measure and control oxygen levels and discover the survival of species and biological production processes. Reductions below the saturation percentage have negative effects on the biodiversity, growth, reproduction and activity of these species. Dissolved oxygen determines whether aerobic or anaerobic organisms prevail in degradation processes, which indicates the ability of water to carry out self-purification processes60.

The concentration of dissolved oxygen in the León River showed variable behavior; a concentration of 5.27mg/L was recorded at station A1, a value higher than that of 3.23mg/L recorded at station A2. This represents a difference of 38.7%, and in the

59 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op. Cit.
60 JOSÉ BENITO VIVES DE ANDREIS INSTITUTE FOR MARINE AND COASTAL RESEARCH (INVEMAR). *Manual de técnicas analíticas para la determinación de parámetros fisicoquímicos y contaminantes marinos* (Manual of analytical techniques for determining physico-chemical parameters and marine contaminants). Ed. Precolombi. Santa Marta, 2003.

case of station A2 potentially indicates the effects of high concentrations of organic matter which might consume the water's dissolved oxygen. Article 2.2.3.3.9.10 of Decree 1076 of 200561 establishes a minimum value of 4.0mg/L regarding the allocation of water for the conservation of flora and fauna. Station A1 is therefore in regulatory compliance, which is not the case for Station A2 which showed below-regulation concentrations. Dissolved oxygen concentrations below 5mg/L may be unable to sustain fish life in bodies of surface water (see Figure 5.40).



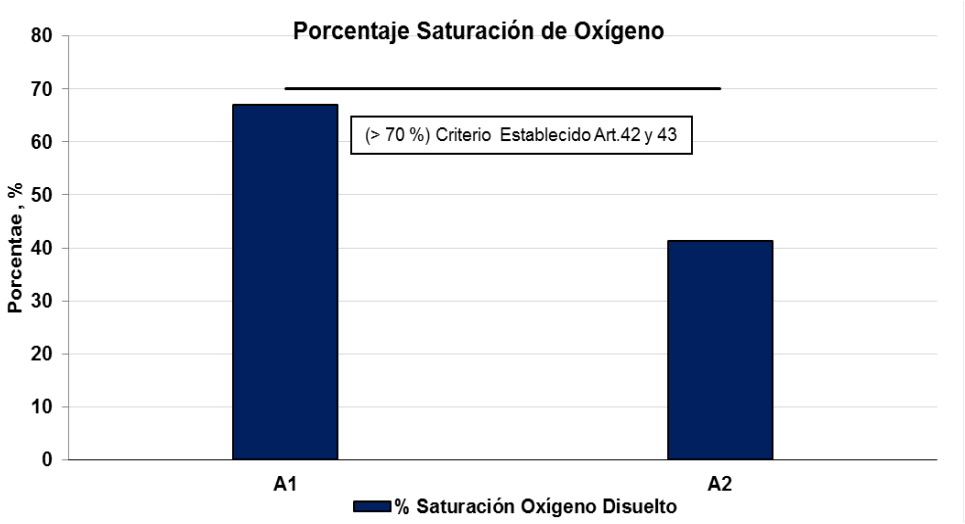
Dissolved oxygen (mg/L) Minimum pH limit- Article 2.2.3.3.9.5

Figure 5.40 Dissolved oxygen results – surface water
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015) with results from *SGS S.A.S* (2015)

The saturation percentage is the amount of dissolved oxygen in water compared with the maximum amount that can be present at the same temperature. This percentage depends on the water temperature and the elevation of the place where the water sample is taken[62].

Sampling station A1 gave a saturation percentage of 67.0% while at station A2 the percentage was lower. The saturation percentage pattern is directly proportional to the concentration of dissolved oxygen; at station A2 the oxygen concentration was low and therefore a low saturation percentage of 41.2% was determined. Decree 1076 of 201563 does not establish a reference value in the aforementioned articles, but saturations below 80% can cause organoleptic alterations of water64 (see Figure 5.41).

61 Ibid.
62 GARCIA, N. M. *Macroinvertebrados acuaticos como sistema de evaluacion de la contaminacion del balneario hurtado*. Bucaramanga, 2010.
63 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op. Cit.
64 RODIER, J. Water Analysis. Omega. 2009.



Oxygen Saturation Percentage
(>70%) criteria established by Article 42 and 43
% Dissolved Oxygen Saturation

Figure 5.41 % Dissolved oxygen saturation results- surface water
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015) with results from *SGS S.A.S* (2015)

❖ Conductivity

Determining conductivity evaluates the ability of water to conduct electric currents, which is an indirect measurement of the number of ions in solution (essentially chloride, nitrate, sulphate, phosphate, sodium, magnesium and calcium)[65].

It is important to mention that any changes to the quantity of dissolved substances, or to the mobility and valence of dissolved ions, will result in conductivity being altered. For that reason, conductivity values are widely used when analyzing water in order to obtain a quick estimate of its dissolved solids content66.

The results presented for the León River showed an “average to increased”[67] degree of mineralization at the stations where samples were taken, due to conductivity values which were determined to be 0.425 mS/cm and 0.283 mS/cm at stations A1 and A2 respectively. This is primarily an indicator of the presence of dissolved ions,

65 GOYENOLA, Guillermo. *Guia para la utilización de las Valijas Viajeras* (Guide to the use of travelling cases) - Network for Participative Environmental Monitoring of Aquatic Systems (RED MAPSA) 2007.
66 ROMERO, J. *Parámetros Fisicoquímicos* (Physico-chemical parameters). In ROMERO, J. *Tratamiento de aguas Residuales* (Treatment of waste water). Bogota., 2009
67 RODIER, J. 2009. Op. Cit.

chlorides and sulphates, which increase water's ability to conduct electrical currents. Decree 1076 of 201568 establishes no regulations for this value.

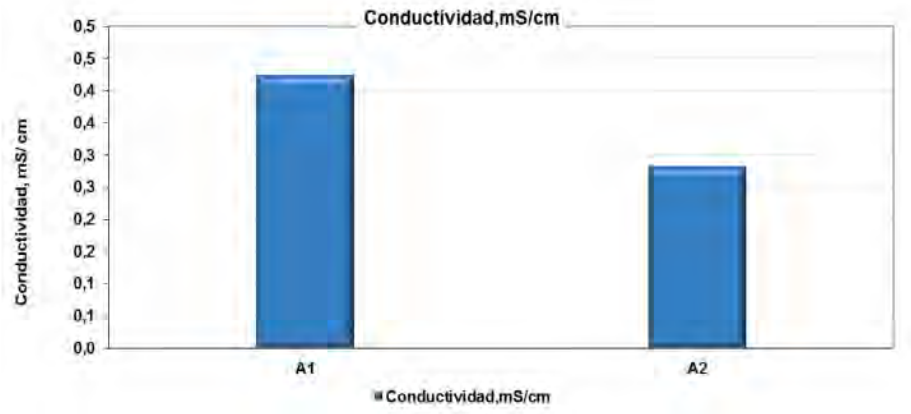


Figure 5.42 Conductivity results- surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015) with results from *SGS S.A.S* (2015)

❖ Total Acidity and Total Alkalinity

The acidity of a water sample determines its ability to neutralize bases, whereas alkalinity measures its ability to neutralize acids. In natural waters, the primary sources of acidity are carbon dioxide originating from the atmosphere and from the bacterial oxidation of organic matter, the mineral acidity of industrial waste and drainage from mines and acid rain[69].

The results for the León River gave total alkalinity values of 66 mg $CaCO_3$/L and 73 mg $CaCO_3$/L for stations A1 and A2 respectively. Acidic substances were found to exist in smaller proportions compared to alkaline substances, giving total acidity results of 11 mg $CaCO_3$/L at station A1 and 15 mg $CaCO_3$/L at station A2 (see Figure 5.43).

68 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op. Cit.
[69] HENRY J. GLYNN and HEINKE GARY. W., Environmental Engineering. Prentice Hall, Mexico, 1999. 800 p

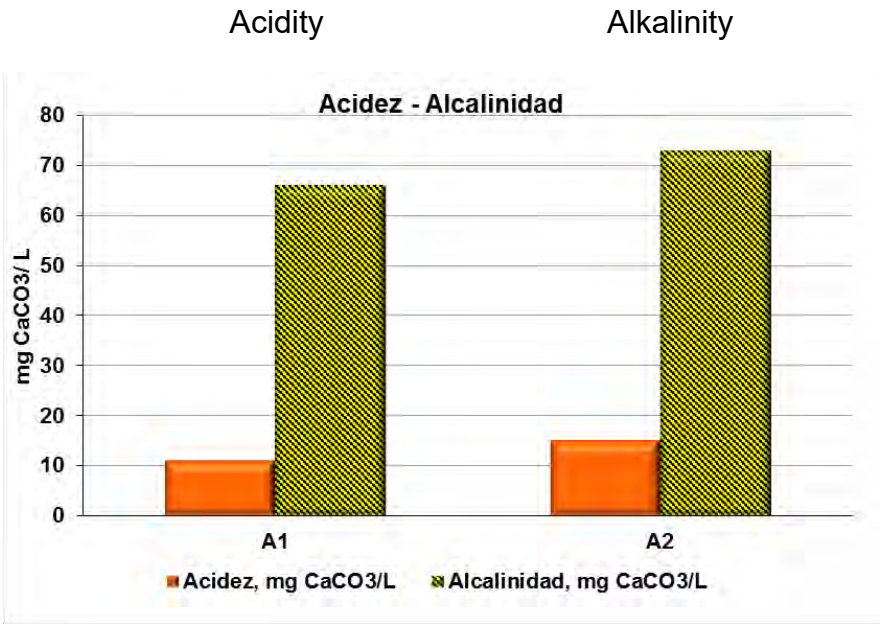


Figure 5.43 Acidity and alkalinity results- surface water
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015) with results from *SGS S.A.S* (2015)

❖ Total Hardness and Calcium Hardness

Significant concentrations were recorded for the total hardness of the waters of the León River, leading to a classification of "moderately hard" (75 –150 mg $CaCO_3$/L) and "very hard" (150 – 300 mg $CaCO_3$/L)[70], with concentrations of 115 mg $CaCO_3$/L and 439 mg $CaCO_3$/L measured at stations A1 and A2 respectively. The concentrations of calcium hardness were 44 mg $CaCO_3$/L (A1) and 194 mg $CaCO_3$/L (A2), primarily linked to the presence of calcium and magnesium salts and bicarbonates, in addition to barium and strontium due to the proximity of the sea (Figure 5.44). Furthermore, these figures were not checked against Colombian regulations as no reference limits for total and calcium hardness have been established, according to the provisions of Decree 1076 of 2015.

70 ROMERO, 2009. Op. Cit.

Calcium Hardness Total Hardness

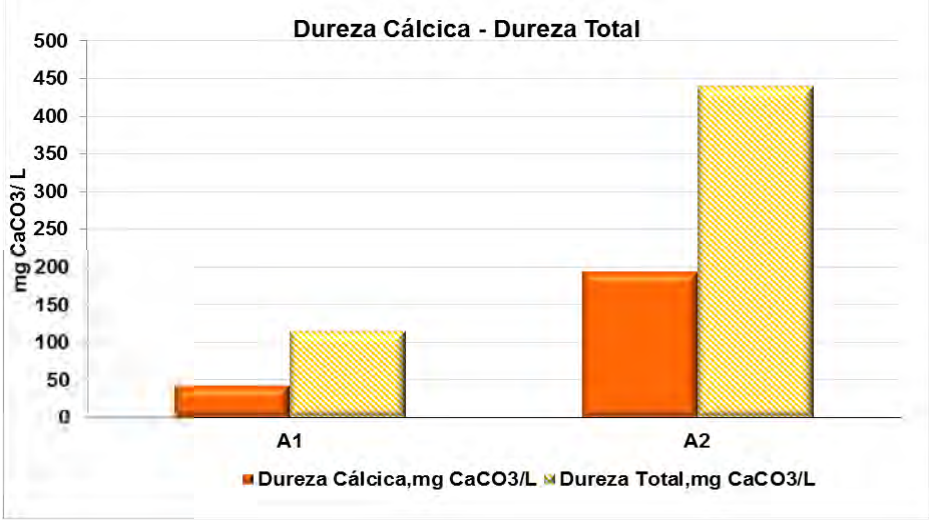
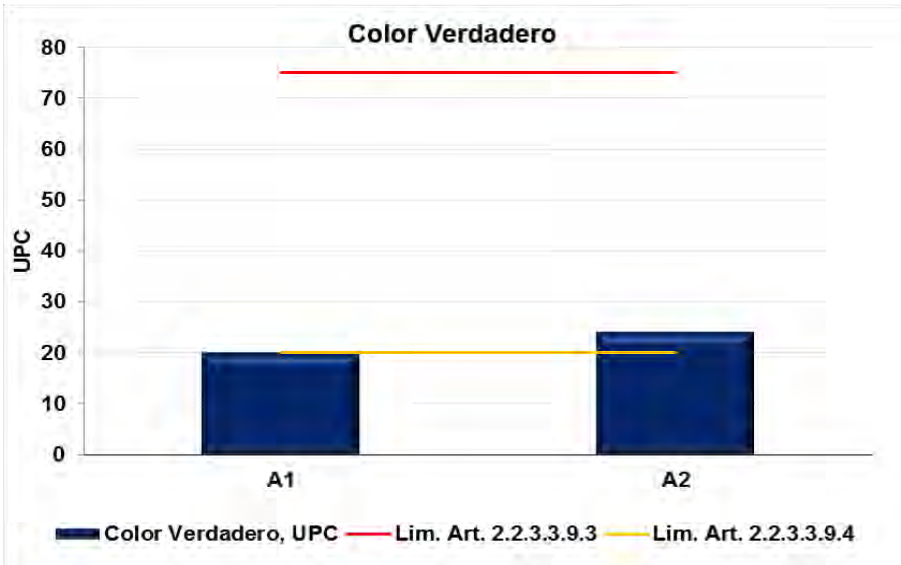


Figure 5.44 Calcium hardness and total hardness results- surface water
Source: ***Aqua & Terra*** *Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

❖ True color

The water's physical appearance showed brownish-yellow coloration, and true color analysis gave values of 20 and 24 UPC for stations A1 and A2 respectively (see Figure 5.45).

True Color



True Color (UPC) Limit- Article 2.2.3.3.9.3 Limit- Article 2.2.3.3.9.4

Figure 5.45 True color results – surface water
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015) with results from *SGS S.A.S* (2015)

❖ Turbidity and Total Suspended Solids

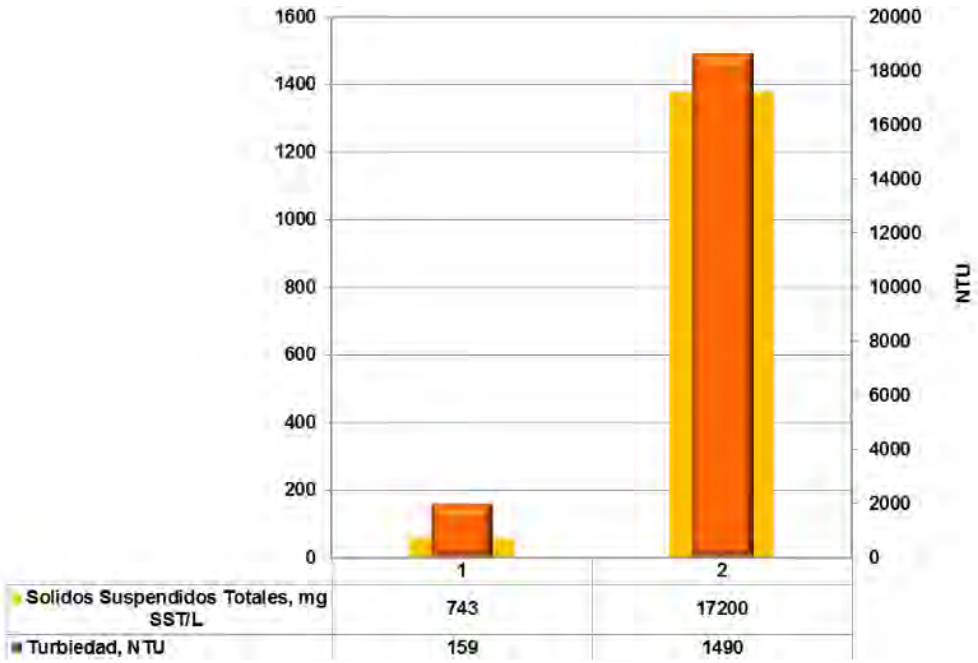
Turbidity is caused by suspended materials such as clay, silt, organic and inorganic matter, planktonic organisms and other microorganisms. It has a direct influence on productivity and the flow of energy within ecosystems, and determines the degree of opacity of water, caused by suspended particulate matter. Given that materials that cause turbidity are also responsible for the water´s color, the concentration of these substances determine the transparency of water by limiting the passage of light through it.[71].

In the results for the León River turbidity stood at 159 NTU, a very low value in comparison with that of station A2 which was determined to be 1490 UPC. This is linked with concentrations of total suspended solids corresponding to 743 mg/L at

71 ROLDAN G. *Bioindicación de la calidad del agua en Colombia* (Bioindication of water quality in Colombia). University of Antioquia Editorial. Medellín. 2003

station A1 and 17,200mg/L at station A2, which are connected with the transportation of sediments (mainly clay and silt) by the strength of the river's current. This statement considers the fact that suspended solids reduce water transparency as electrostatic repulsion causes them to remain suspended (see Figure 5.46).

It should be mentioned that, during the sampling process carried out on the León River, maintenance dredging activities were taking place at station A2 (downstream from the river) to guarantee navigability for ships transporting bananas to the anchorage at Bahía Colombia in the Gulf of Urabá. This factor could have caused the variations in concentrations of both total suspended solids and turbidity with regards to station A1, which is situated upstream from station A2.



Total Suspended Solids
Turbidity

Figure 5.46 Turbidity and Total Suspended Solids results- surface water
Source: *Aqua & Terra Consultores Asociados S.A.S. (*2015) with results from *SGS S.A.S* (2015)

❖ Sedimentable Solids and Total Dissolved Solids

Low concentrations of sedimentable solids were reported, of 2.0 ml/L at station A1 and 0.2 ml/L at station A2. With regards to suspended solids a notable difference

was observed, with the highest concentration (17200 mg/L) being recorded for station A2 compared with a concentration of 743 mg/L for station A1. Finally, the highest concentrations of total dissolved solids were recorded at station A1 (176 mg/L), while concentrations of 148mg/L were recorded for station A2 (see Figure No. 5.47).

Additionally, and as mentioned in the previous section, dredging activities on the León River were seen taking place close to the water quality sampling site at station A2. This is a potential reason for the difference in concentrations at both stations.

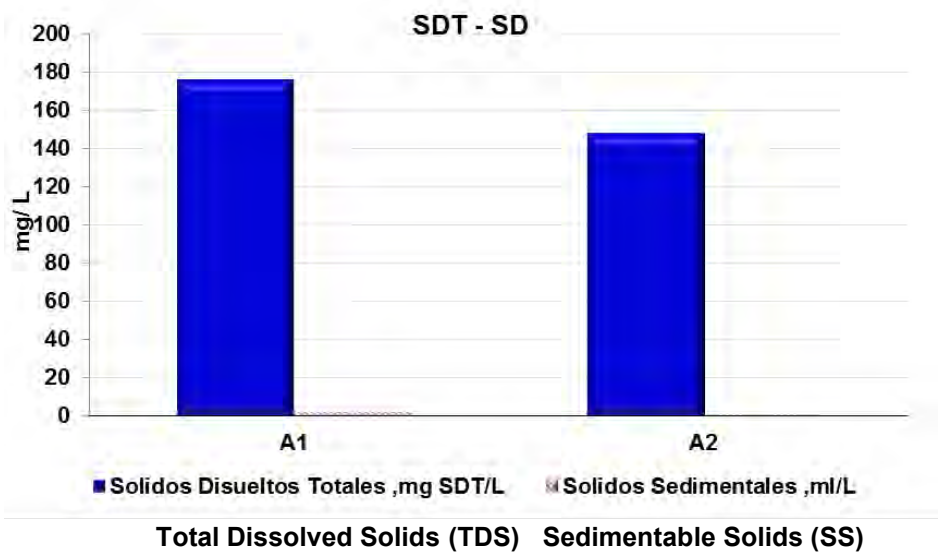


Figure No. 5.47 Sedimentable Solids and Total Dissolved Solids results- surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

❖ Total Phenols and Fats and Oils

Fats and oils are organic compounds that are primarily made up of fatty acids of animal and plant origin. Some of their most representative characteristics include low density, low water solubility and low or zero biodegradability. As a consequence, if left uncontrolled they accumulate in water and form scum on the surface. The effect of fats and oils on natural water is caused by their interference with the exchange of gases between water and the atmosphere. They prevent the free passage of oxygen into water as well as the passage of CO2 from water into the atmosphere, and in extreme cases can combine with low levels of dissolved oxygen to cause the acidification of water, in addition to hindering the penetration of sunlight. The main

contributory sources of fats and oils are households, automotive workshops, the engines of ships and motorboats, meat processing plants and the oil and cosmetics industries[72].

According the results obtained for the León River pertaining to organic parameters, the concentrations of total phenols, fats and oils were below the detection limit of the analytical technique employed. This indicates that these compounds exist in low concentrations, giving results of less than 0.075mg/L for total phenols and less than 0.8mg/L for fats and oils.

- **Chemical and Biochemical Oxygen Demand**

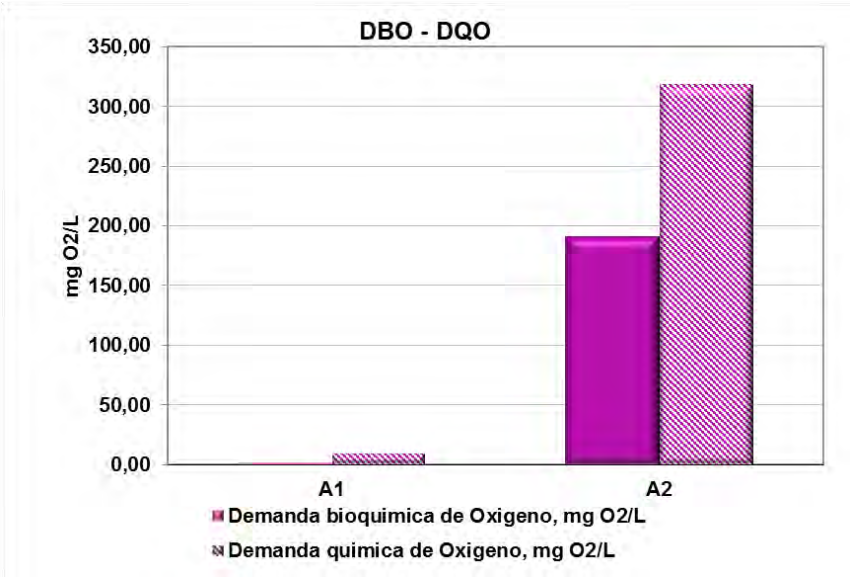
Also known as biological oxygen demand, biochemical oxygen demand (BOD) is normally defined as the amount of oxygen required by bacteria during the stabilization of organic matter susceptible to decomposition. A BOD test is used to determine the polluting power of domestic and industrial waste with regards to the amount of oxygen they require when discharged into watercourses where aerobic conditions exist.

Chemical oxygen demand refers to the amount of oxygen necessary for the chemical decomposition of organic and inorganic matter. It is often used to measure contaminants in natural and waste water, and to evaluate the strength of residues such as municipal and industrial waste water.

According the results of sampling, the chemical oxygen demand (COD) values reported for station A1 were below 10 mg/L, which is the minimum detection limit of the technique used. The opposite occurred at station A2, where the value given for the parameter was 319 mg O_2/L. The BOD test$_5$ showed the same pattern, recording <2 mg O_2/L at station A1 and 191 mg O_2/L at station A2, which could be attributed to high concentrations of easily biodegradable organic compounds and organic compounds that require oxidation by means of chemical substances (see Figure 5.48). The variations in concentrations at both stations can be linked to the resuspension of sediment due to dredging activities in the area of station A2 on the León River, which could bring about an increase in contaminants in the water column.

BOD – COD

72 ARCE A. L: *Serie Autodidactica de medición de la calidad de agua* (Autodidactic measurement series of water quality). Collection and Control Management of the General Administrative Subdirectorate for Water. Mexico, 2015.



Biochemical oxygen demand
Chemical oxygen demand

Figure 5.48 BOD5-COD– surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

❖ Total Phosphorus

Phosphorus is an essential component of the biological cycle in bodies of water and, generally speaking, is the agent that limits the growth of algae and aquatic plants in freshwater wetlands. This means that concentrations of phosphorus can be used as a criterion to identify problems of eutrophication in lakes, lagoons or rivers, and to determine the eutrophic state of a body of water73.

The total phosphorus concentrations reported at station A1 were 2.24mg/L, compared with 13.4mg/L at station A2 (see Figure 5.49). This could potentially be linked to the agricultural activity that takes place in the area using fertilizers, where phosphorus contaminants bound to soil particles are washed away by run-off.

Total Phosphorus

73 UNIVERSITY OF COSTA RICA. In Tropical Biology Magazine. 1999.

Figure 5.49 Total Phosphorus results - surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

❖ Total and Fecal Coliforms

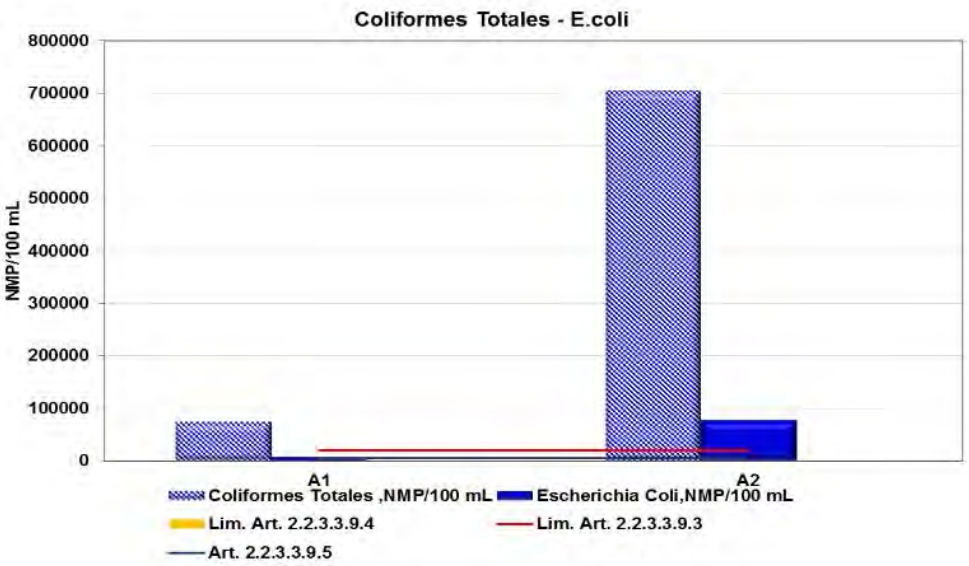
Analysis of total coliform bacteria and *Escherichia Coli* identified high populations of these microorganisms at the sampling stations. As *Escherichia Coli* is present in the digestive tract of warm-blooded animals and human beings, this is an indicator of recent fecal contamination.

Figure 5.50 shows the quantities of the two bacteria that were identified at the two stations along the León River, with higher concentrations recorded for station A2 than for station A1. The concentration of total coliforms stood at 73,800 NMP/100ml at station A1 and 703,000NMP/100ml at station A2. Likewise, fecal coliforms were more prevalent at station A2, with concentrations of 75,000NMP/100ml compared with 7,400NMP/100ml at station A1. This indicates that the waters of the León River show pollution caused by untreated domestic waste, which makes sense given that the León River receives the discharge of the rivers Porroso, Juradó (Mutata), Guapá (Chigorodó), Carepa, Vijagual, Zungo, Apartado and Grande. Commercial export agriculture takes place on the plains of these rivers, generating the highest amounts of domestic waste originating from human settlements.

With regard to Colombian regulatory compliance (Decree 1076 of 201574), the amount of total coliforms exceeded the values stipulated in Articles 2.2.3.3.9.3 with a limit of 20,000NMP/100ml (Conventional treatment and quality criteria for human and domestic consumption), in Article 2.2.3.3.9.4 with a limit of 1,000NMP/100ml (Disinfection and quality criteria for human and domestic consumption) and in Article

74 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op Cit.

2.2.3.3.9.5 with a limit of 5,000NMP/100ml (Quality criteria for agricultural use). This indicates that the conventional treatment and disinfection of water of this type is not sufficient to make it suitable for human consumption. For agricultural use, it cannot be used for directly irrigating short-stemmed vegetables or any fruit that is eaten unpeeled. Article 2.2.3.3.9.10 (quality criteria for the conservation of flora and fauna) establishes no limit for this parameter, which suggests that the water can be allocated for this use.



Total Coliforms
Limit- Article 2.2.3.3.9.4
Article 2.2.3.3.9.5

Escherichia Coli
Limit- Article 2.2.3.3.9.3

Figure 5.50 Total Coliforms and E coli results – surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

❖ Traces of Heavy Metals

Metals are important constituents in many types of water; some are classified as polluting substances, but a number of them are of great importance in the normal functioning of ecosystems and the growth of algae.

Some of the potentially most toxic chemical components are Sb, As, Cd, Cu, Cr, Hg, Ni, Pb, Se and Zn, which enter the water cycle from a variety of sources. One such source is lithogenic or geochemical in origin, arising from minerals which are washed into water due to erosion or rainfall. However, the greatest concentration is of anthropogenic origin due to human activity. Mining, industrial processes and

domestic waste are significant sources of pollution, contributing metals to the air, water and, in particular soil[75].

The water quality analysis of the León River included testing for barium, total cadmium, total copper, total chromium, total mercury, total nickel, total silver, total lead, total selenium, total arsenic and total zinc. Very low concentrations were found of each, in the order of the traces.

The concentrations of mercury, arsenic and silver found were below the detection limit of the analytical technique used in the laboratory. The analysis gave concentration results of less than 0.00027 mg/L for mercury, <0.010 mg/L for arsenic and <0.0004 mg/L for silver.

With regards to regulatory compliance, the values for cadmium, mercury, nickel, silver, lead, arsenic and zinc comply with the provisions of Articles 2.2.3.3.9.3 (Conventional treatment and quality criteria for human and domestic consumption), 2.2.3.3.9.4 (Disinfection and quality criteria for human and domestic consumption) and 2.2.3.3.9.5 (Quality criteria for agricultural use) of Decree 1076 of 201576.

The amount of copper is in compliance with Articles 2.2.3.3.9.3 (1.0 mg/L for conventional treatment and quality criteria for human and domestic consumption) and 2.2.3.3.9.4 (1.0 mg/L for disinfection and quality criteria for human and domestic consumption); however, despite station A1 being in compliance, the value at station A2 exceeds the limit permitted in Article 2.2.3.3.9.5 (Quality criteria for agricultural use).

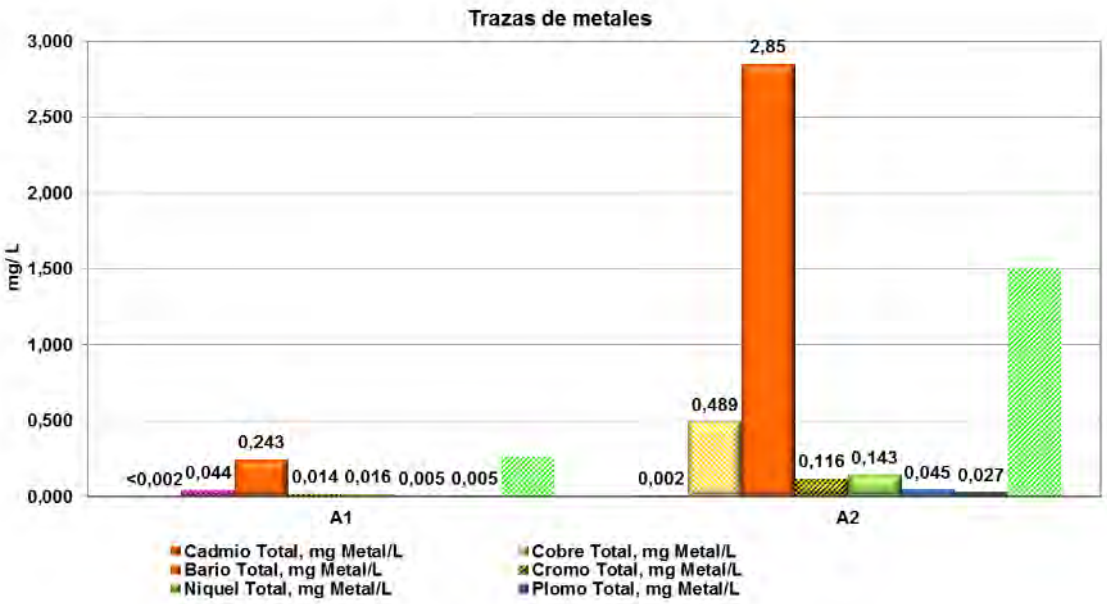
The concentrations of selenium comply with the provisions of Articles 2.2.3.3.9.3 (1.0 mg/L for conventional treatment and quality criteria for human and domestic consumption) and 2.2.3.3.9.4 (1.0 mg/L for disinfection and quality criteria for human and domestic consumption). However, at station A2 the amount exceeds the limit permitted in Article 2.2.3.3.9.5 (0.02 mg/L) for livestock use with a result of 0.027 mg/L.

No reference value is given for total chromium. The already-mentioned presence of pollutants could be linked to domestic and industrial discharge into the body of water (see Figure 5.51).

The concentrations of barium recorded were 0.24 and 2.85mg/L at stations A1 and A2 respectively. In terms of compliance with Decree 1076 of 201577, barium levels

75 ROSAS RODRÍGUEZ, H. *Estudio de la contaminación por metales pesados en la cuenca del Llobregat* (Study into contamination by heavy metals in the Llobregat basin). Spain, 2001.
76 COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op Cit.
77. COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). Op. Cit.

at station A1 are in compliance with Articles 2.2.3.3.9.3 (with a limit of 1 mg/L for conventional treatment and quality criteria for human and domestic consumption) and 2.2.3.3.9.4 (with a limit of 0.01 mg/L for disinfection and quality criteria for human and domestic consumption). On the other hand, the values recorded at station A2 exceed the regulatory limits of the aforementioned articles, which indicates that the water at that location cannot be allocated for human use without prior treatment.



Total Cadmium	Total Copper
Total Barium	Total Chromium
Total Nickel	Total Lead

Figure 5.51 Trace Metals – surface water
Source: *Aqua & Terra Consultores Asociados S.A.S.,* 2015 with results from *SGS S.A.S*, 2015

- Comparison with national and international law

Results were compared against Colombian law, which establishes permissible water quality limits for the allocation of the resource for different uses, in accordance with Decree 1076 of 2015[78]. This legislation is a Single Regulatory Decree from the Environment and Sustainable Development sector, in Chapter 3, Section 9

78 Ibid.

(Transitional provisions for uses of water and quality criteria for its uses), in the following articles:

- Article 2.2.3.3.9.3. Conventional treatment and quality criteria for human and domestic consumption.
- Article 2.2.3.3.9.4. Disinfection and quality criteria for human and domestic consumption.
- Article 2.2.3.3.9.5. Quality criteria for agricultural use.
- Article 2.2.3.3.9.10. Quality criteria for the conservation of flora and fauna.

Given that Colombian law sets no permissible limits for some parameters, special water quality analysis for metals was carried out using Canadian Water Quality Guidelines for the Protection of aquatic life79, and the Environmental Quality and Effluent Discharge Standard: Water Resource – Book VI Appendix 1 (TULAS-Ecuador)80

79 CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT – CCME. Canadian water quality guidelines for the protection of aquatic life: Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving Numerical Water Quality Objectives. In: Canadian environmental quality guidelines, 1999. [Online] < http://ceqg-rcqe.ccme.ca/en/index.html> [Accessed September 11th, 2015]

80 PRESIDENT OF THE REPUBLIC OF ECUADOR. ENVIRONMENT MINISTRY OF ECUADOR. Executive Decree 3516 (March 31st, 2003). (Regulations of the environmental law for preventing and controlling pollution and its technical laws). Book VI Appendix 1. (Environmental quality and effluent discharge law: water resources). Quito, 2003.

Table 5.17 Comparison of results with standards Station A1 and A2

ANÁLYSIS	Results		Decree 1076 of 2015				Compliance
			Art. 2.2.3.3.9.3	Art. 2.2.3.3.9.4	Art. 2.2.3.3.9.5	Art. 2.2.3.3.9.10	
	A1	A2	Conventional treatment and quality criteria for human and domestic consumption.	Disinfection and quality criteria for human and domestic consumption.	Quality criteria for agricultural use	Conservation of Flora and Fauna	
pH, units	5.45	5.69	5.00 – 9.00	6.5 – 8.5	4.5 – 9.0	6.5 – 8.5	A1 & A2 in compliance with Art. 2.2.3.3.9.3 - 2.2.3.3.9.10; not in compliance with Art. 2.2.3.3.9.4 - 2.2.3.3.9.10
Dissolved oxygen, mg/L	5.27	3.23	N.S.	N.S.	N.S.	5.0	A1 in compliance - A2 not in compliance
True Color, UPC	20	24	75	20	N.E.	N.S.	A1 in compliance with Art. 2.2.3.3.9.3 - 2.2.3.3.9.4 A2 in compliance with Art. 2.2.3.3.9.3, not in compliance with Art. 2.2.3.3.9.4
Total Phenols, mg/L	<0.075	<0.075	0.002	0.002	N.S.	1.0 CL*	N.D.**
Fats and oils, mg F&O/L	<0.8	<0.8	N.S.	N.S.	N.S.	0.01 CL	N.D **
Total coliforms ,NMP/100 ml	73800	703000	20000	1000	5000	N.S.	Not in compliance
Total Barium, mg Metal/L	0.24	2.85	1.0	1.0	N.S.	0.1 CL*	A1 in compliance with Art. 2.2.3.3.9.3 - 2.2.3.3.9.4 A2 not in compliance with Art. 2.2.3.3.9.3 - 2.2.3.3.9.4
Total Cadmium, mg Metal/L	<0.002	0.002	0.01	0.01	0.01	0.1 CL*	In compliance
Total Copper, mg Metal/L	0.04	0.490	1.0	1.0	0.2	0.1 CL*	In compliance
Total Mercury, mg Metal/L	<0.00027	<0.00027	0.002	0.002	N.S.	0.01 CL*	In compliance
Total Nickel, mg Metal/L	0.02	0.14	N.S.	N.S.	0.2	0.01 CL*	In compliance

ANÁLYSIS	Results		Decree 1076 of 2015				Compliance
			Art. 2.2.3.3.9.3	Art. 2.2.3.3.9.4	Art. 2.2.3.3.9.5	Art. 2.2.3.3.9.10	
	A1	A2	Conventional treatment and quality criteria for human and domestic consumption.	Disinfection and quality criteria for human and domestic consumption.	Quality criteria for agricultural use	Conservation of Flora and Fauna	
Total Silver, mg Metal/L	<0.0004	<0.0004	0.05	0.05	N.S.	0.01 CL*	In compliance
Total Lead, mg Metal/L	0.01	0.05	0.05	0.05	5.0	0.01 CL*	In compliance
Total Selenium, mg Metal/L	0.01	0.03	0.01	0.01	0.02	0.01 CL*	A1 in compliance with Art. 2.2.3.3.9.3 - 2.2.3.3.9.4 - 2.2.3.3.9.5. A2 not in compliance
Total Arsenic, mg Metal/L	<0.010	<0.010	0.05	0.05	0.1	0.1 CL*	In compliance
Total Zinc, mg Metal/L	0.26	1.51	15.0	15.0	2.0	0.01 CL*	In compliance

*The regulatory criteria for the metals established in Article 2.2.3.3.9.10 of Decree 1076 of 2015 are provided. However, no comparison was made as it only applies to bioassays.
**The detection limit of the analytical technique is above the regulatory limit, and therefore it cannot be determined whether the value is in compliance or not.
N.S.: Not specified
Source: SGS Colombia S.A.S (July 2015)

Table 5.18 Comparison of results against foreign reference regulations

ANÁLYSIS	Results		TULAS Environmental Quality and Discharge Standard	Canadian Law for Protecting Aquatic Life Long term	COMPLIANCE
	A1	A2	Use: Conservation of Fauna and Flora		
Total Barium, mg Metal/L	0.24	2.85	1.0	N.S.	A2 Not in compliance
Total Cadmium, mg Metal/L	<0.002	0.002	0.001	0.00009	Not established by Canadian law **

					A2 Not in compliance with TULAS A1 Not established**
Total Copper, mg Metal/L	0.04	0.49	0.02	N.S.	Not in compliance with TULAS
Total Chromium, mg Metal/L	0.01	0.12	0.05	N.S.	A2 Not in compliance with TULAS.
Total Mercury, mg Metal/L	<0.00027	<0.00027	0.0002	0.000026	. Not established by TULAS and Canadian law**
Total Nickel, mg Metal/L	0.02	0.14	0.025	N.S.	A2 not in compliance with TULAS
Total Silver, mg Metal/L	<0.0004	<0.0004	0.01	N.S.	In compliance with TULAS
Total Selenium, mg Metal/L	0.01	0.03	0.01	N.S.	A2 not in compliance with TULAS
Total Arsenic, mg Metal/L	<0.010	<0.010	0.05	0.005	In compliance with TULAS Not established by Canadian law **
Total Zinc, mg Metal/L	0.26	1.51	0.18	0.3	Not in compliance

**** The detection limit of the analytical technique is above the regulatory limit, and therefore it cannot be determined whether the value is in compliance or not**

Source: SGS Colombia S.A.S (July 2015)

- Environmental Quality Indexes

Additionally, we will analyze the water quality of the León River using quality indexes such as the ICE, the saturation or Langelier index and the Potential Alteration of Water Quality Index (IACAL, ICOMI, ICOMO and ICOSU), which employs a single expression to determine water quality from the results of several physicochemical and bacteriological parameters which in the past were analyzed individually.

❖ Environmental Quality Index – ICA

The ICA is a quality indicator with the full title of "ICA-NSF Water Quality Index", and is one of the most commonly used indicators to determine the quality of bodies of surface water. To that end, we must use and combine several parameters: the dissolved oxygen percentage, pH, BOD5, turbidity and total solids. Other parameters such as nitrates and phosphates were not identified, and fecal coliform values were not presented in the units that the calculation requires. Nevertheless, the index was calculated using the values available for the León River.

The water quality index calculations for stations A1 and A2 of the León River are presented in Table 5.19 and Table 5.20.

Table 5.19 Water Quality Index – Station A1

A1				
Parameter	**Result**	**Quality Value**	**Weighting**	**Index Total**
% Saturation of dissolved oxygen	67.0	70	0.17	**50 Poor Quality**
pH, Units	5.45	40	0.11	
BOD_5, mg/L	2	80	0.11	
Turbidity, NTU	159	5	0.08	
Total Solids	919	20	0.07	

Source: *Aqua & Terra Consultores Asociados, S.A.S, 2015*

Table 5.20 Water Quality Index – Station A2

A2				
Parameter	**Result**	**Quality Value**	**Weighting**	**Index Total**
% Saturation of dissolved oxygen	41.2	32	0.17	**24 Very poor Quality**
pH, Units	5.69	46	0.11	
BOD_5, mg/L	191	5	0.11	

A2				
Parameter	**Result**	**Quality Value**	**Weighting**	**Index Total**
Turbidity, NTU	1490	5	0.08	
Total Solids	17348	20	0.07	

Source: *Aqua & Terra Consultores Asociados, S.A.S, 2015*

In accordance with the ICE Water Quality Index values and their respective colors (presented in the (presented in the methodology section in Chapter – General of this study), the water quality at quality at station A1 stood within the 25-50 range and was classified as being of ***"poor quality"***. ***"poor quality"***. The water quality at station A2 was between the 0-25 range, classifying it in the classifying it in the ***"very poor"*** quality category (ICA

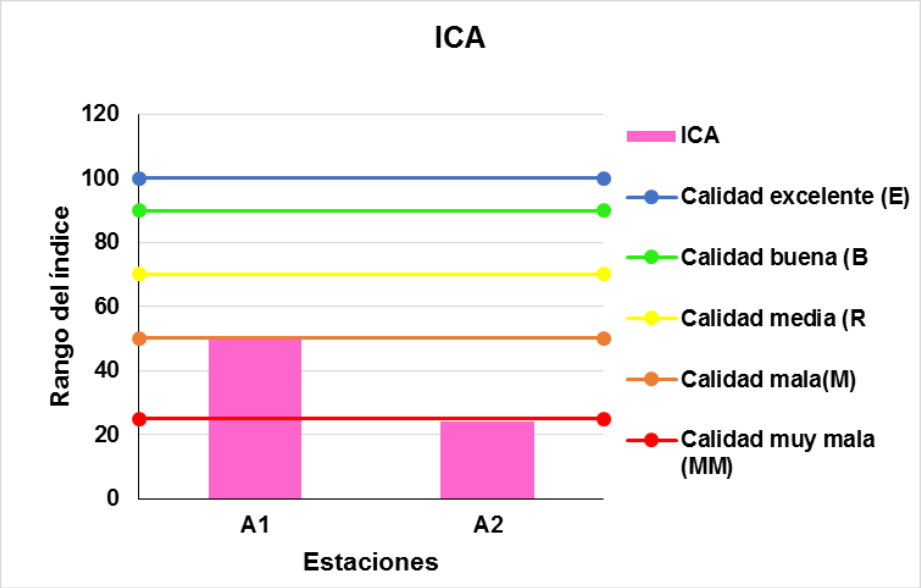
Index range

Excellent quality
Good quality
Average quality
Poor quality
Very poor quality

Station

Figure No. 5.52).

These results were expected, given that in the area of study the León River is a body of water affected by human intervention, and is itself fed by several watercourses upstream from the site where the sampling took place. This could be linked to the presence of export agriculture and human settlements close to the river's banks.



ICA
Excellent quality
Good quality
Index range Average quality
Poor quality
Very poor quality

Station

Figure No. 5.52 ICA Water Quality Index
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S,* 2015

❖ Saturation or Langelier Index

Below, the results regarding pH, temperature, total hardness and total alkalinity are used as a basis for determining the Langelier Index for both of the sampling stations along the León River (Table 5.21). The index was calculated according to the methodology presented in Chapter 2- General.

Table 5.21 Langelier Index Result

Station	pH	TEMPERATURE	TOTAL HARDNESS	TOTAL ALKALINITY	ISL	Classi-fication

		Temp (°C)	Temperature Coefficient. °C	Total Hardness(mg/L)	Hardness Coefficient (mg/L)	Total Alkalinity (mg/L)	Alkalinity Coefficient (mg/L)		
A1	5.45	27.8	0.6442	115	1.6652	66	1.8264	-2.51	**Corrosive Water**
A2	5.69	28	0.648	439	2.249	73	1.87	-1.64	**Corrosive Water**

Source: *Aqua & Terra Consultores Asociados, S.A.S,* 2015

According to the calculation performed, the water of the León River was classified as corrosive, which is coherent with the acidic pH shown at both stations analyzed along the watercourse.

❖ Potential Alteration of Water Quality Index (IACAL)

The National Water Study[81] estimates the Potential Alteration of Water Quality Index (IACAL) for average and dry water conditions, representing the results of this indicator of potential pressure due to quality contaminating loads by hydrographic subareas. Information from this study was taken as a reference for the project's area of study.

The study area is located on the León River, in the Caribbean-Urabá subarea, which has a total supply of 4.526 billion cubic meters (Mm^3) in an average year and 1.488 billion cubic meters (Mm^3) in a dry year. As can be seen in Figure 5.53 and Figure 5.54, the Potential Alteration of Water Quality Index gave a result of "**high**" for both dry and average years. This is one of the subareas under greatest pressure from pollutants in the Department of Antioquia.

[81] INSTITUTE OF HYDROLOGY, METEOROLOGY AND ENVIRONMENTAL STUDIES (IDEAM), ENVIRONMENT, HOUSING AND TERRITORIAL DEVELOPMENT MINISTRY (MAVDT) National Water Study. Bogotá, 2014. 493p. ISBN: 978-958-8067-70-4.sub

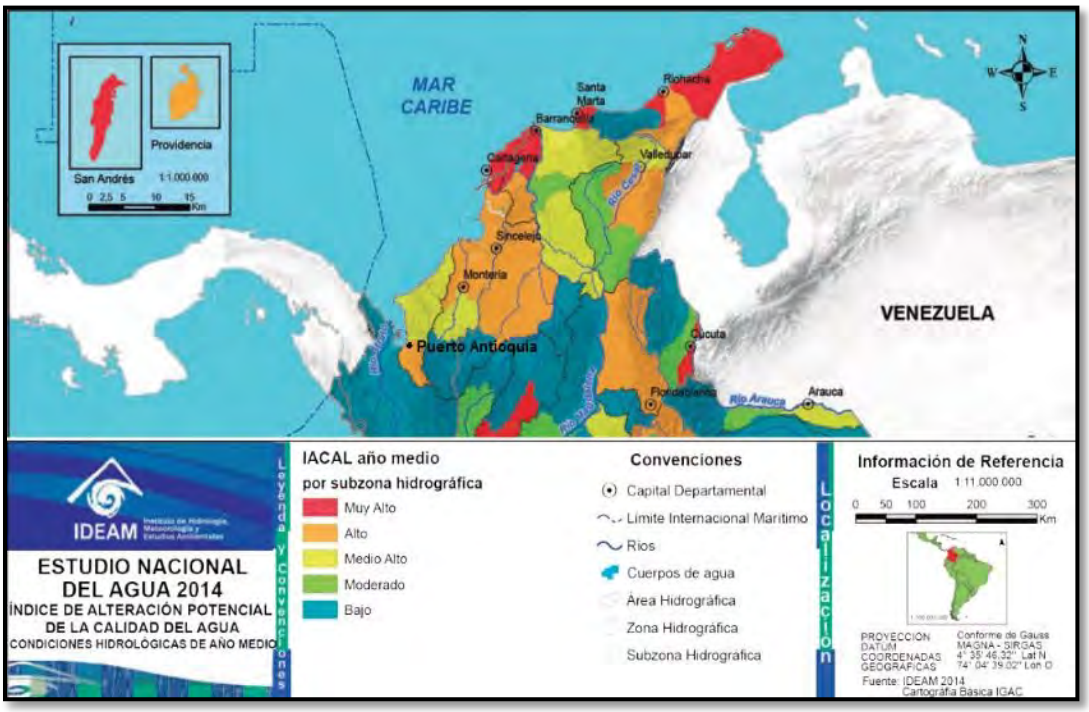


Figure 5.53 Potential Alteration of Water Quality Index (IACAL) - Average year
Source: ENA 2014[82], modified by *Aqua & Terra Consultores Asociados S.A.S,* 2015

[82] Ibid.

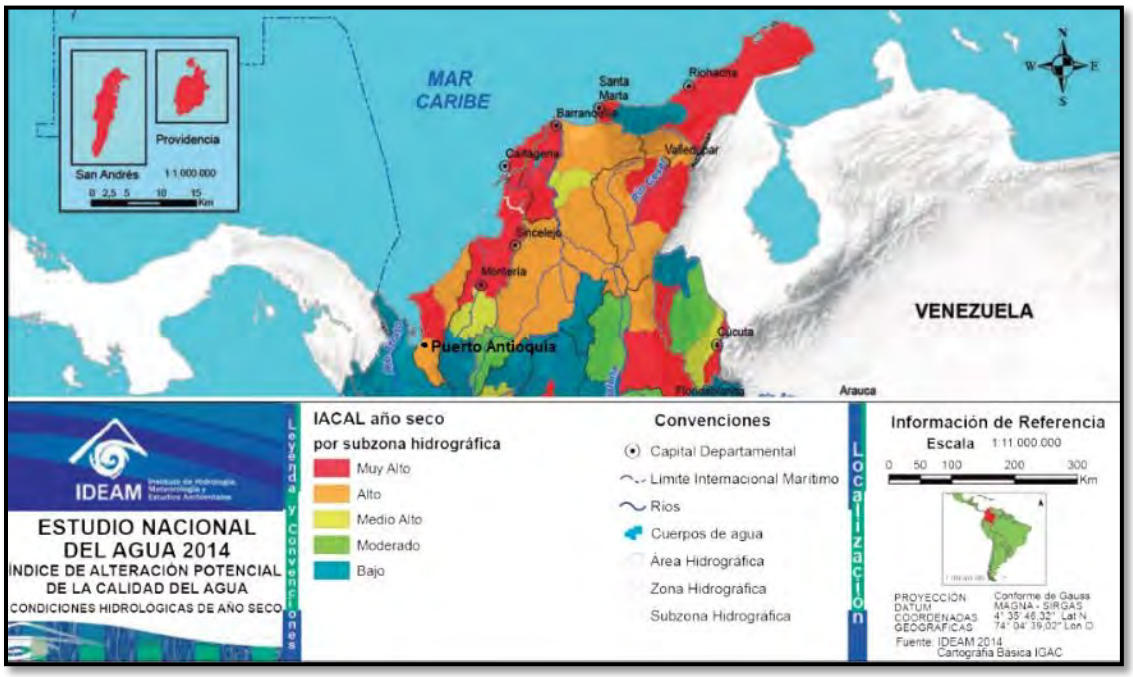


Figure 5.54 Potential Alteration of Water Quality Index (IACAL) - Dry year
Source: ENA 2014[83] modified by *Aqua & Terra Consultores Asociados S.A.S,* 2015

❖ Contamination by Mineralization Index (ICOMI)

The ICOMI Contamination by Mineralization Index includes variables such as conductivity, hardness and alkalinity, and was calculated according to the methodology presented in Chapter 2- General of this study.

Table 5.22 shows the results given by the mineralization index. Both stations were categorized as having "high" contamination by mineralization, an expected result given that the analyzed variables showed significant concentrations. Conductivity showed above-normal concentrations for the lower basin; in terms of hardness the water was classified as hard and very hard, albeit within permissible levels for human supply[84].

[83] Ibid.
[84] RAMÍREZ, Alberto; VIÑA, Alberto. (Colombian Limnology: contributions to knowledge and statistical analysis). Printed in Colombia, 1998.

Table 5.22 ICOMI Index Results

Station	ICOMI Index	Classification
A1	0.69	High (0.6 - 0.8)
A2	0.71	High (0.6 - 0.8)

Source: *Aqua & Terra Consultores Asociados, S.A.S,* 2015

❖ Contamination by Organic Matter Index (ICOMO)

The ICOMO Contamination by Organic Matter Index includes variables such as the percentage of dissolved oxygen, total coliforms and biochemical oxygen demand, and was calculated according to the methodology presented in Chapter 2 (General) of this study.

The organic matter index results obtained for the stations along the León River are presented in Table 5.23. Different classifications were given for each station: station A1 was determined to have a "medium" level of contamination, and station A2 was classified as having "very high" contamination. This difference may be linked to the influence of suspended material generated by maintenance dredging activities (carried out to ensure that the banana freight that travels through the area is able to navigate) on the León River at the time the samples were taken. The difference in levels of contamination may also be linked to the discharge of untreated domestic water generated by the human settlements upstream from the sampling site. The León is one of the rivers with the highest microbial load, represented by coliforms (2.6×10^{20} t/year) and linked to the discharge of domestic waste water[85].

Table 5.23 ICOMO Index Results

Station	ICOMO Index	Classification
A1	0.44	Medium (>0.4 - 0.6)
A2	0.86	Very High (>0.8 - 1)

Source: *Aqua & Terra Consultores Asociados, S.A.S*, 2015

❖ Contamination by Suspended Solids Index (ICOSUS)

The Contamination by Suspended Solids Index was calculated according to the methodology presented in Chapter 2 (General) of this study.

In accordance with the above, the results obtained at the stations along the León River were then checked. Station A1 showed concentrations of 743 mg/L and station

[85] JOSÉ BENITO VIVES DE ANDREIS INSTITUTE FOR MARINE AND COASTAL RESEARCH (INVEMAR), MONITORING NETWORK FOR THE CONSERVATION AND PROTECTION OF SEA AND COASTAL WATER IN COLOMBIA (REDCAM) ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY (MADS). *Diagnóstico y evaluación de la calidad de las aguas marinas y costeras del caribe y pacifico colombianos* (Diagnosis and evaluation of the quality of sea and coastal water in the Colombian Pacific and Caribbean). Santa Marta, 2015. 316 p.. ISSN: 2389-8615

A2 gave results of 17,200 mg/L. These results were compared with the index classification (which gives an ICOSUS index of 1 for concentrations higher than 340 mg/L) and indicate that the water has "very high" levels of suspended solids (see Table 5.24). Again, these results may be linked to the maintenance dredging activities that are constantly carried out along the León River to ensure navigability for banana freight, and to the transportation of sediment due to erosive action on the river bed.

Table 5.24 ICOSUS Index Results

Station	ICOMO Index	Classification
A1	1	Very High (>0.8 - 1)
A2	1	Very High (>0.8 - 1)

Source: *Aqua & Terra Consultores Asociados, S.A.S,* 2015

- *Secondary Historical Information on the Quality of Inland and Sea Water (REDCAM)*

Furthermore, in order to assess the quality of sea and inland water, data was taken from five (5) monitoring stations (see Figure 5.55) belonging to the Inland and Sea Water Quality Network (REDCAM) of the José Benito Vives de Andréis Coastal and Marine Research Institute (INVEMAR)[86]. One of the stations was located on the León River and the rest were at the mouth of the León River and in Bahía Colombia.

The historical average of the data recorded at the stations during the rainy and dry seasons between 2001 and 2014 (see Figure 5.55) was calculated in order to compare the historical bacteriological and physicochemical characteristics with those recorded during the sampling campaign held on July 7th and 8th, 2015. The stations' location coordinates are included in the methodology in *Chapter 2 (General)* of this environmental license modification study.

86 JOSÉ BENITO VIVES DE ANDREIS INSTITUTE FOR MARINE AND COASTAL RESEARCH (INVEMAR), MONITORING NETWORK FOR THE CONSERVATION AND PROTECTION OF SEA AND COASTAL WATER IN COLOMBIA (REDCAM) [Online] < http://siam.invemar.org.co/siam/redcam/estadisticas/index.jsp> [Accessed September 12th, 2015]

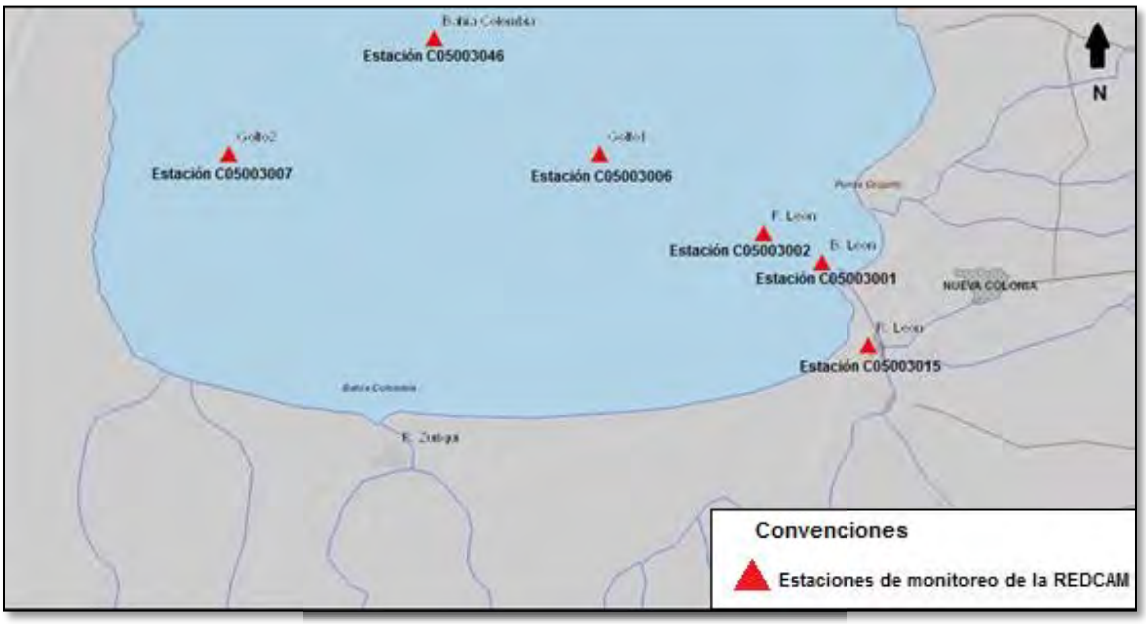


Figure 5.55 Location of REDCAM monitoring stations- inland and sea water quality
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

❖ Historical Results

The results of the historical averages from the five (5) REDCAM stations for both the rainy and dry seasons are shown overleaf in Table 5.25. The stations were selected due to their being the closest to the area where the project will be carried out.

Table 5.25 Results from REDCAM stations for the rainy and dry seasons in Bahía Colombia and the León River

Parameter		Unit	Station C05003015 Km upstream from the León River-DGI014		Station C05003001 Mouth of the León River-DGI013		Station C05003002 (Front) Km after León River - DGI015		Station C05003006 Gulf of Urabá-DG001		Station C05003007 Gulf of Urabá - DG002		Station C05003046 Bahía Colombia	
			Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Temperature	TEM	ºC	27.53	28.58	27.78	28.77	29.10	28.63	_	28	_	28	28.84	28.525
pH	pH	Unit	7.00	7.27	7.17	7.19	7.67	7.76	_	7.98	_	8	7.312	7.5775
Dissolved Oxygen	DO	mg/l	3.62	3.77	3.65	4.23	4.62	6.34	_	6.62	_	7.2	4.655	6.7075
Turbidity	TUR	NTU	762.35	65.10	225.63	126.06	974.38	25.46	_	_	_	_	2.9	10.8525
Conductivity	CON	mS/cm	11.64	17849.27	17.67	19920.20	32.19	162.58	_	8.8	_	10	29.424	15.525
Salinity	SAL	º/oo	0.04	1.62	0.34	3.25	16.00	6.58	_	5	_	5	13.4	7.5
Biochemical Oxygen Demand	BOD	mg/l	1.24	1.65	1.41	1.35	1.10	1.38	_	0.74	_	1.73	1.188	0.84
Nitrates	NO3	µg/l	98.53	104.62	132.06	326.74	116.77	113.23	_	4.1	_	6.8	6.65	93.66667
Nitrites	NO2	µg/l	11.10	20.47	10.78	25.01	126.10	5.71	_		_		3.8	2.7
Orthophosphates	PO4	µg/l	226.10	170.33	267.79	151.11	88.94	91.39	_	3	_		62.2	47.875
Ammonium	NH4	µg/l	114.09	181.93	151.21	168.38	4.50	145.91	_	233.6	_	208	125	185.63
Total Suspended Solids	TSS	mg/l	394.35	97.70	240.65	171.38	1641.77	39.54	_	_	_	1	72	10.75
Dissolved and Dispersed Hydrocarbons	DDH	µg/l	0.48	3.00	0.22	0.76	0.13	1.99	_	_	_	_	3.5227	0.0103
Cadmium	CD	µg/l	0.25	1.07	0.66	0.48	0.65	0.87	_	_	_	_	0.1	0.14
Lead	PB	µg/l	22.44	3.81	3.38	3.64	19.06	2.91	_	4.82	_	5.37	2.47	0.415
Mercury	HG	µg/l	3.28	4.11	1.04	6.35		4.17					4.60127	4.395

Parameter		Unit	Station C05003015 Km upstream from the León River-DGI014		Station C05003001 Mouth of the León River-DGI013		Station C05003002 (Front) Km after León River - DGI015		Station C05003006 Gulf of Urabá-DG001		Station C05003007 Gulf of Urabá - DG002		Station C05003046 Bahía Colombia	
			Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Iron	FE	µg/l	4.55	2.95	9.41	3.45	0.81	1.04	_	_	_	_	0.71	0.6725
Total Coliforms	CTT	NMP/100 ml	33581.5	967030.7	1148255.4	14518.5	916094.0	2186.0	_	_	_	_	96	402.5
Thermotolerant Coliforms	CTE	NMP/100 ml	865100.0	299288.6	281308.3	107023.1	56538.6	6708.6	_	_	_	_	39.8	115

Source: REDCAM[87]

87 Ibid.

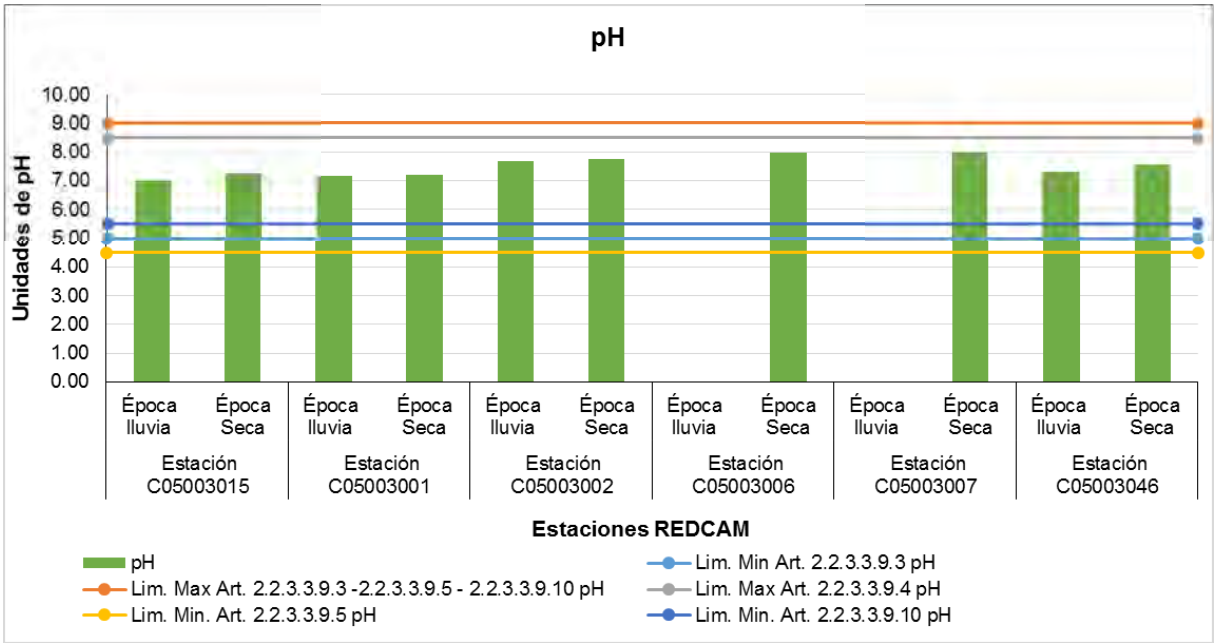
❖ Analysis of Water Quality Results from REDCAM Stations

Analysis is provided below of the historical physicochemical and bacteriological parameters for the station on the León River and the stations in Bahía Colombia. These stations are the closest to the facilities that will be built for the project, and their results are analyzed to enable comparisons to be made between current conditions and those recorded in previous periods.

- *pH Units*

pH concentrations at all the stations in the rainy and dry seasons proved to be very similar, with average pH units of 7.63 and 7.29 respectively. A minimum pH concentration of 7 was recorded in the rainy season and a maximum of 8 units was recorded in the dry season.

When these concentrations are compared against Decree 1076 of 2015[88], the reported values fall within the ranges established in Articles 2.2.3.3.9.7 and 2.2.3.9.7.8 for recreational purposes with primary and secondary contact, and Article 2.2.3.3.9.10 for flora and fauna conservation purposes. This indicates that the water is not restricted for these uses and shows no effect on the aquatic biota (see Figure 5.56).



[88] COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Decree 1076 (May 26th, 2015). (Issuing the Single Regulatory Decree of the Environmental and Sustainable Development Sector). Section 3 (Quality criteria for allocating the resource). Bogotá D.C., 2015

Época lluvia = rainy season
Época seca = dry season
Unidades de pH = pH units
Estación = station

REDCAM stations

Maximum limit- Article 2.2.3.3.9.3….
Minimum limit- Article 2.2.3.3.9.5

Minimum limit- Article 2.2.3.3.9.3
Maximum limit- Article 2.2.3.3.9.4
Minimum limit- Article 2.2.3.3.9.10

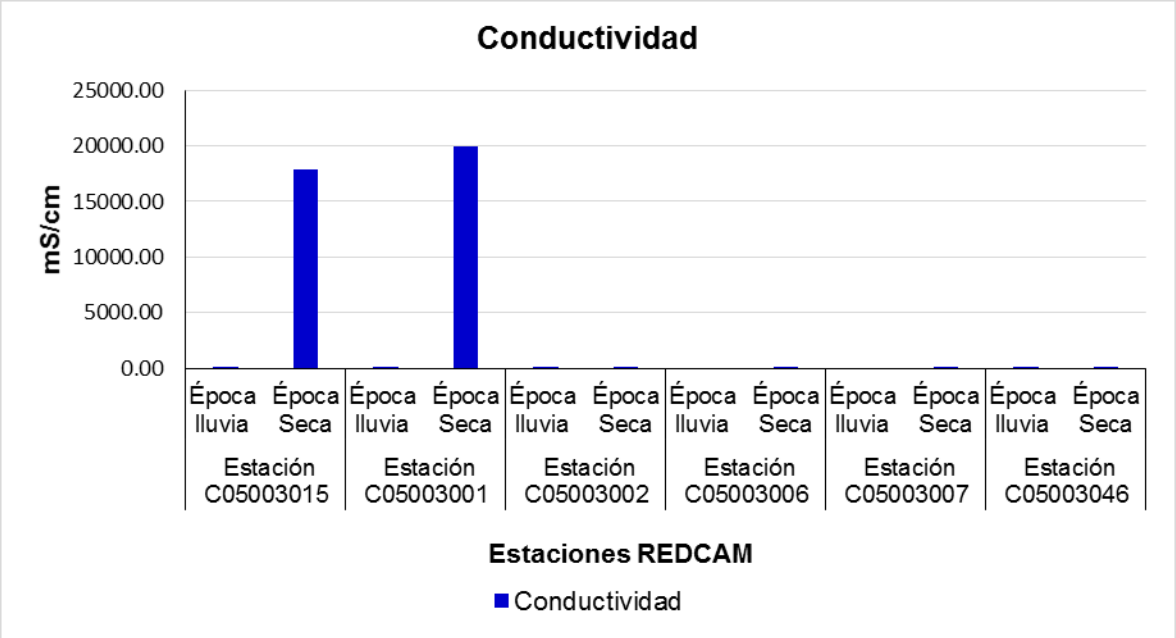
Figure 5.56 pH (Rainy and dry season)
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

- *Conductivity*

A rainy-season average of 14.65mS/cm was given for the stations located on the León River. Extremely high conductivity levels were shown at these stations in the dry season, with an average of 18884.73mS/cm and a maximum value of 19920.20 mS/cm recorded at the mouth of the León River.

Meanwhile, the average conductivity recorded at the stations in the Gulf of Urabá was 30.8mS/cm during the rainy season. However, during the dry season there proved to be significant differences between the stations: the station closest to the mouth of the León River (C05003002-1 km to the front) showed conductivity of 162.58 mS/cm, while the Gulf of Urabá stations DG001, DG002 and Bahía Colombia gave conductivity results of 8, 10 and 15.25 mS/cm respectively (see Figure 5.57)

Conductivity



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Figure 5.57 Conductivity (Rainy and dry season)
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

The extreme values recorded at the stations on the León River during the dry season could be linked to the continuous maintenance dredging activities that are carried out to ensure that ships are able to navigate the León River. These actions cause sediment to become resuspended, thus producing high amounts of suspended solids which in turn have a direct bearing on conductivity in the water[89]

There is also a possibility that these spikes in conductivity are due to sensor error, if one bears in mind that the measurements of total suspended solids were lower during the period when the extreme conductivity values were recorded.

- *Temperature*

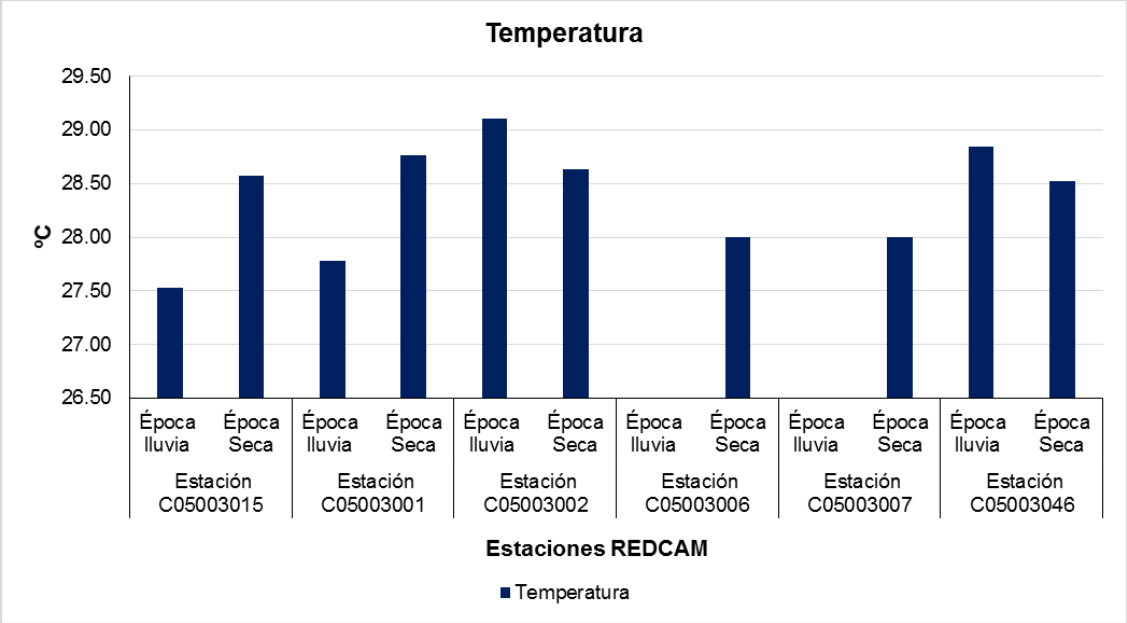
The temperature of the samples taken during the rainy season show an average of 28.3°C compared with an average of 28.4°C taken during the dry season. This

[89] Hanna Instruments. (2013). (What relationship exists between conductivity and total dissolved solids?) Accessed on October 1st, 2015, at http://www.hannainst.es/blog/cual-es-la-relacion-existente-entre-la-conductividad-y-los-solidos-totales-disueltos/

demonstrates a large degree of uniformity in water temperature during both seasons. The minimum value of 27.53°C was recorded in the rainy season and the maximum value recorded in the dry season was 28.77°C (see Figure 5.58).

If REDCAM data is compared to the information obtained by SGS when carrying out monitoring at seven (7) points of the Gulf of Urabá in 2015, a difference of -0.64°C becomes apparent with regards to the average water temperature of 29.04°C. This figure was obtained from the results of the laboratory that monitored the water quality and marine sediment in the area.

Temperature



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Figure 5.58 Temperature – Rainy and Dry Season
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

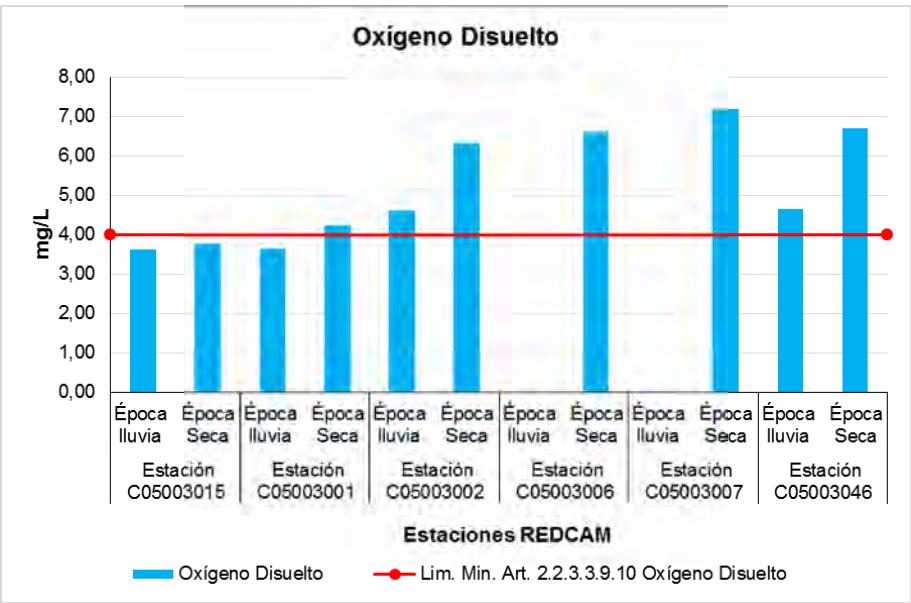
- *Dissolved Oxygen*

The average concentrations of dissolved oxygen recorded at the REDCAM stations on the León River and in its estuary were 4.0mg/L in the dry season and 3.63mg/L in the rainy season. At the stations located in the Gulf of Urabá the average

concentrations fluctuate between 6.72 and 4.64mg/L in the dry and rainy seasons respectively.

According to the quality criteria for the conservation of flora and fauna (Article 2.2.3.3.9.10. of Decree 1076 of 2015), the minimum concentration of dissolved oxygen for both warm fresh water and sea or estuary water is 4.0mg/L. When REDCAM data is compared with these criteria the concentrations of dissolved oxygen in the León River are shown to be below the minimum level. In the case of the Gulf of Urabá, the concentrations of dissolved oxygen recorded exceed the minimum limit defined by Colombian law (see Figure 5.59)

Dissolved Oxygen



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Dissolved Oxygen **Minimum limit- Article 2.2.3.3.9.10 Dissolved Oxygen**

Figure 5.59 Dissolved Oxygen – Rainy and Dry Season

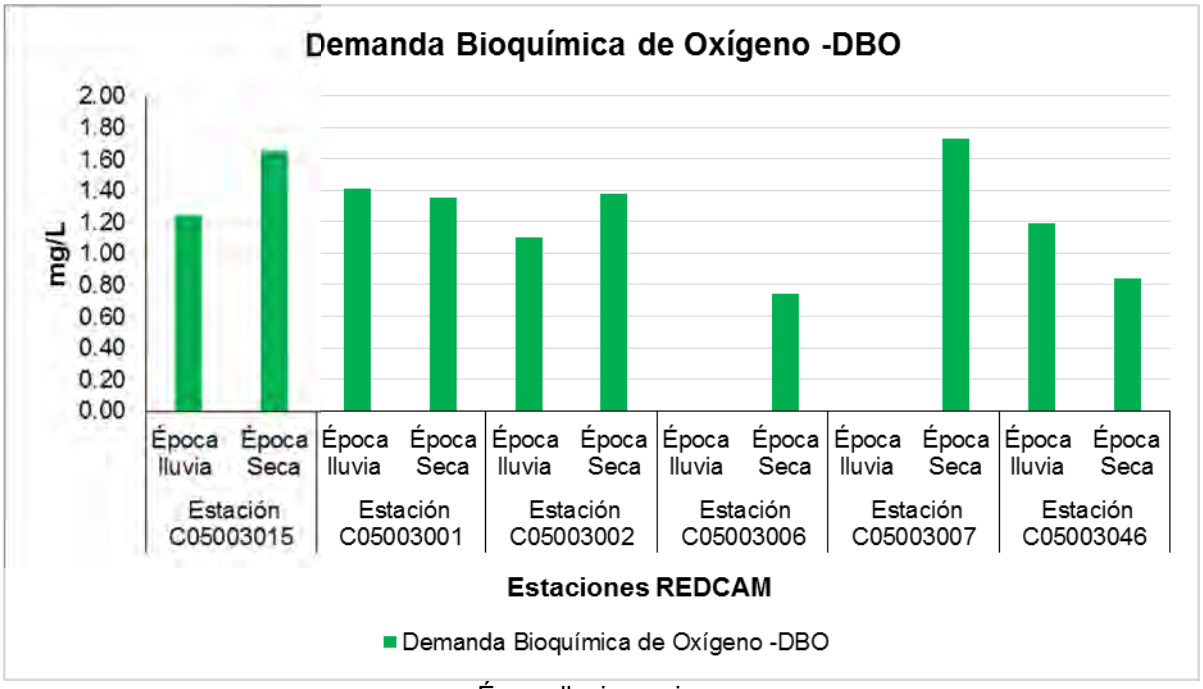
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

- *Biochemical Oxygen Demand*

The average BOD during the dry season at the stations on the León River stands at 1.50mg/L, dropping to 1.33mg/L during the rainy season. The stations located in Bahía Colombia gave BOD results of 0.99mg/L in the dry season and 1.14mg/L in the rainy season. The lowest BOD value recorded was 0.74mg/L, corresponding to the dry season.

Figure 5.60 shows the data taken from REDCAM, except that which corresponds to the rainy season at stations DG-001 and DG-002 in the Gulf of Urabá.

Biochemical Oxygen Demand- BOD



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Figure 5.60 Biochemical Oxygen Demand – Rainy and Dry Season
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

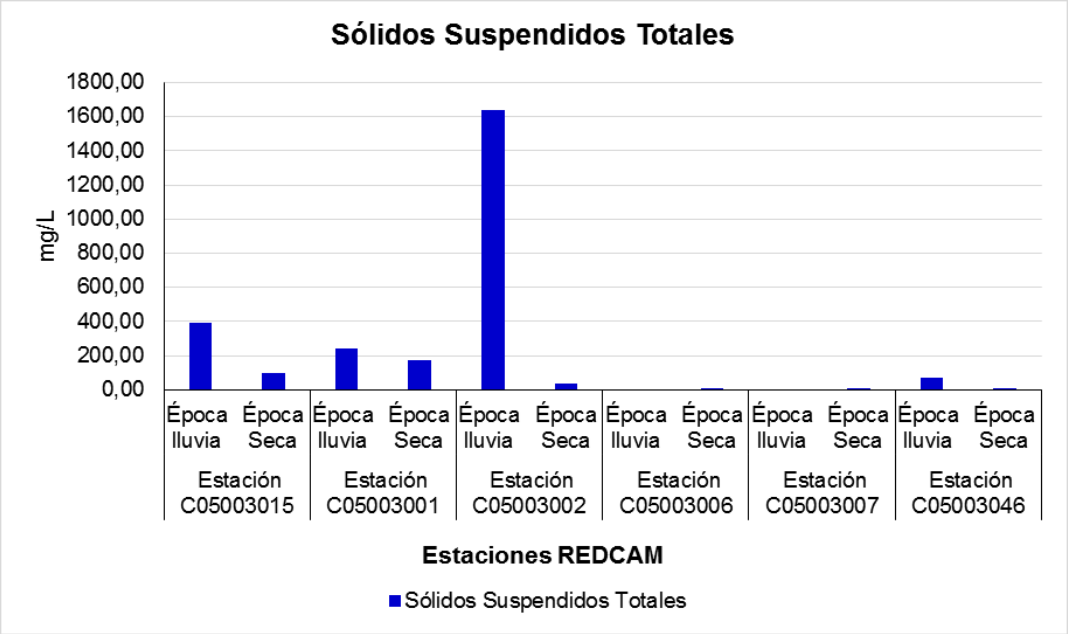
- *Total Suspended Solids - TSS*

The TSS recorded by the stations 1km before the estuary of the León River and in its estuary show average rainy season values of 317.5mg/L compared with a dry season average of 134.54mg/L. The maximum value stands at 394.5mg/L in the rainy season, and the minimum recorded was 97.70mg/L in the dry season.

In terms of the stations located in the Gulf of Urabá and Bahía Colombia area, during the dry season there was a noticeable difference between the station situated 1km in front of the estuary of the León River (where TSS concentrations were 39.54mg/L) and the other stations in the Gulf (with TSS concentrations of 3.00, 1.00 and 10.75mg/L). The same pattern occurs during the rainy season, with the station close to the estuary of the León River (C05003002) showing concentrations of 1641.77mg/L, the highest value recorded among the Gulf stations. On the other hand, the Bahía Colombia station (C05003046) showed concentrations of 72mg/L. The lowest concentration was 1.00mg/L, recorded at station C05003007 during the dry season.

These high TSS values (primarily recorded at the stations on the León River, in its estuary and 1km in front of its estuary) may be associated with the continuous maintenance dredging activities, and the erosive processes and transportation of sediment that take place along the watercourse, to later be dispersed upon arrival in the Gulf of Urabá.

Total Suspended Solids



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM Stations

Figure 5.61 Total Suspended Solids – Rainy and Dry Season
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

- *Total and Thermotolerant Coliforms*

Microbiological measurements taken at the stations located on the León River, its estuary and 1km in front of its estuary showed particularly high amounts of total coliforms (CTT). The CTT values at the three aforementioned stations during the rainy season averaged 976,483NMP/100ml, with a maximum value of 1,148,255 NMP/100ml at station C05003001 and a minimum value of 865,100 NMP/100 ml at station C05003015.

With regard to the dry season, average coliform levels of 360,254NMP/100ml were measured at the same stations. The maximum value of 967,030NMP/100ml was recorded at station C05003015 and the minimum dry season value was 6,708NMP/100ml, measured at station C05003002.

No information on this parameter is available for stations C05003006 and C05003007 in the Gulf of Urabá. This means that the only information available corresponds to station C05003046, where total coliform levels of 96.00NMP/100ml in the rainy season and 402.5NMP/100ml in the dry season were recorded. These values are significantly lower than those recorded at the stations along the León River.

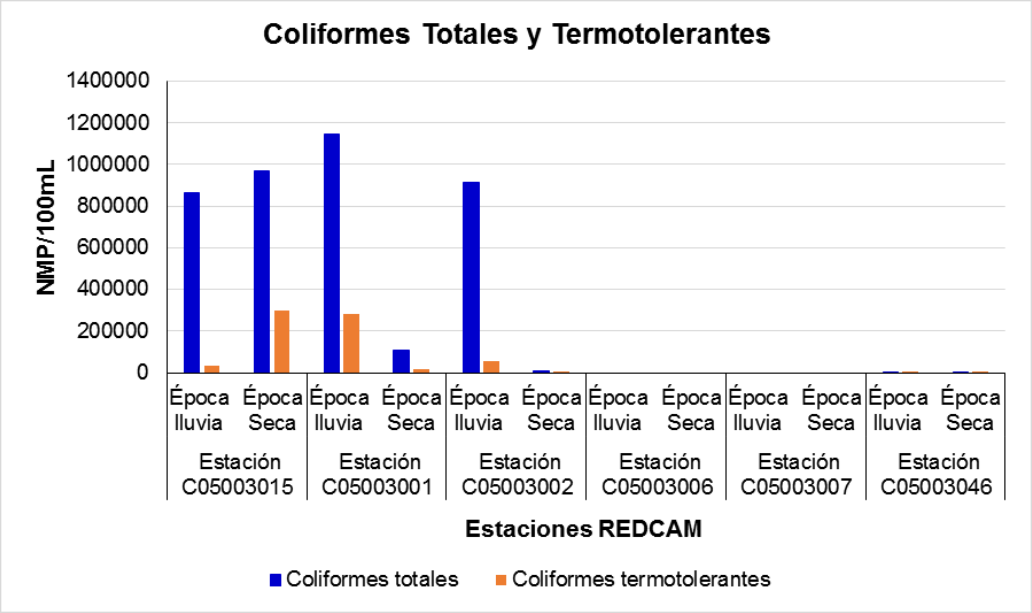
If these results are compared against Articles 2.2.3.3.9.7. and 2.2.3.3.9.8 of Decree 1076 of 2015, regarding water quality criteria for recreational purposes through primary and secondary contact respectively, it is clear that the measurements taken at the stations on the León River (1km upstream from the estuary, in the estuary and 1km in front of the estuary) are well above the maximum permissible limits of 1,000 NMP/100ml for primary contact and 5,000NMP/100ml for secondary contact. That is, the water in this section of river should not even be used for recreational activities that do not involve immersion, such as rowing, fishing, wading or rafting, among others.

The levels of thermotolerant coliforms (CTE) are in proportion to the quantities of CTT detected. For this reason, the highest values were seen at the stations on the León River, with an average of 123,809NMP/100ml during the rainy season. In the dry season, CTE levels are of the order of 299,288NMP/100ml at the station on the León River; measurements of 14,581NMP/100ml and 2,186NMP/100ml were taken in the estuary and at the station in front of the estuary respectively.

According to the measurements taken by station C05003046, CTE levels in the Gulf of Urabá stand at 39NMP/100ml during the rainy season and 115 NMP/100ml during the dry season.

Figure 5.62 shows the previously mentioned information presented in graph form.

Total and Thermotolerant Coliforms



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Total Coliforms ` Thermotolerant coliforms

Figure 5.62 Total and Thermotolerant Coliforms – rainy and dry seasons
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

As mentioned at the beginning of the chapter, the REDCAM microbiological results reflect high levels of human intervention in the catchment area of the León River, where domestic waste water is discharged with no form of treatment.

- *Traces of Metals*

The trace metals identified from the available REDCAM data were cadmium (Cd), iron (Fe), mercury (Hg) and lead (Pb). As their name suggests, these elements were detected in trace amounts in the column of water, with higher concentrations at the stations on the León River compared with the stations located in the Gulf of Urabá.

Lead was the trace metal found in the highest concentrations. At the stations on the León River the average rainy season concentration was 0.0150 mg/L, compared with a concentration of 0.0035 mg/L during the dry season. The maximum

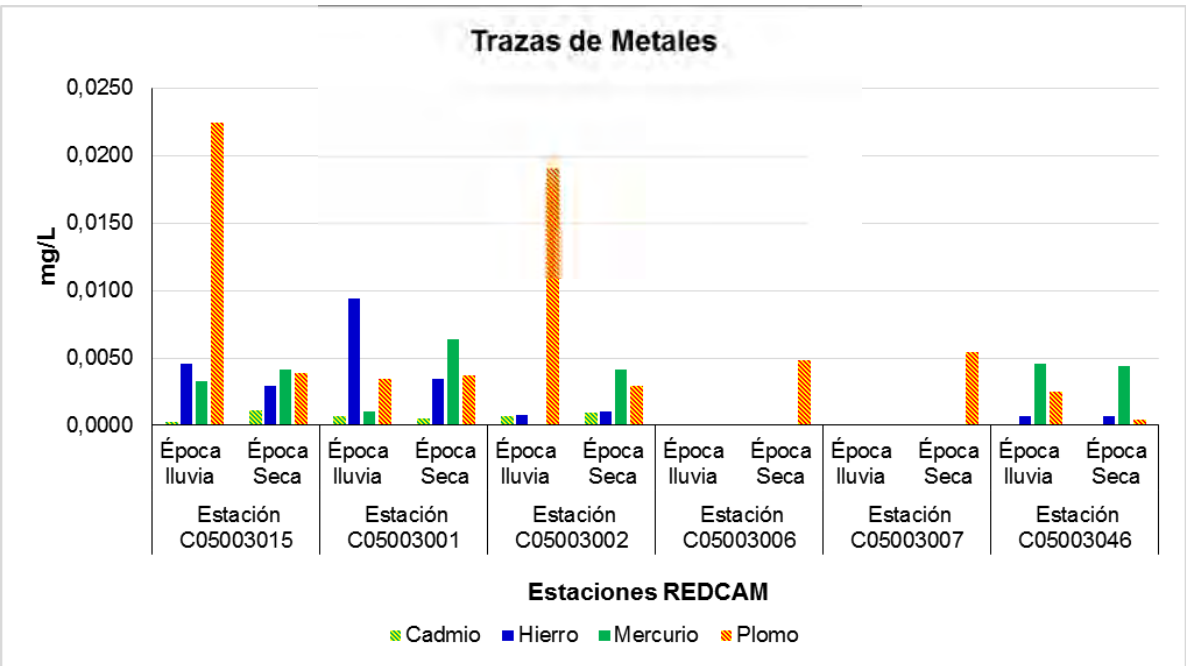
concentration found was 0.022mg/L in the rainy season, with a minimum concentration of 0.0029mg/L measured during the dry season.

With regards to cadmium, the average value recorded at the stations on the León River was 0.0005 mg/L in the rainy season and 0.0008 mg/L in the dry season. Of the stations situated in the Gulf of Urabá, only information corresponding to station C05003046 is available, which showed concentrations of 0.0001mg/L for both the rainy and dry seasons.

At the stations on the León River, mercury concentrations of 0.0022 mg/L and 0.0049 mg/L were found in the rainy and dry seasons respectively. Similar levels were detected at station C05003046 in the Gulf of Urabá, standing at 0.0046 mg/L in the rainy season and 0.0044 mg/L in the dry season.

Finally, the iron levels detected at the stations on the León River were found to fluctuate, with around 0.0049 mg/L in the rainy season and 0.0025 mg/L in the dry season. The measurements taken for the station in the Gulf of Urabá were 0.0007 mg/L for both seasons. (see Figure 5.63)

Traces of Metals



Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Cadmium Iron Mercury Lead

Figure 5.63 Traces of Metals- rainy and dry season

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

The trace metal data obtained from REDCAM was compared with the water quality criteria for the conservation of flora and fauna issued by Ecuador's Environment Ministry and the Canadian Council of Ministers of the Environment presented in Table 5.26.

Table 5.26. International water quality criteria for the conservation of flora and fauna

Parameter	Units	Ecuadorean Law[90]		Canadian Law[91]		
				Fresh water		Sea water
		Warm fresh water	Sea and estuary water	Short term	Long term	Long term
Cadmium	mg/L	0.001	0.005	0.001	0.00009	0.00012
Iron	mg/L	0.3	0.3	-	0.3	-
Mercury	mg/L	0.0002	0.0001	-	0.000026	0.000016
Lead	mg/L	-	0.01	-	-	-

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015

The results obtained at the station on the León River show that during the rainy and dry seasons, only mercury was found in concentrations that exceed the maximum limits of both standards.

In the Gulf of Urabá, stations C05003001, C05003002 and C05003046 showed concentrations of mercury above what is established in both of the international regulations used as references.

Cadmium was the other element to exceed the permissible limits determined by the regulations, doing so at stations C05003001 and C05003002 in both the dry and rainy seasons.

[90] Decree 3.516 - *Norma de Calidad Ambiental y de descarga de efluentes: recurso agua* (Environmental quality and effluent discharge law: water resources) (Appendix I, Book VI: On environmental quality, from the unified text of the secondary legislation of the Environment Ministry).

[91] Canadian Council of Minister of the Environment. (2014). Canadian Water Quality Guidelines for the Protection of Aquatic Life: Summary Tables. Winnipeg.

Finally, the concentration of lead recorded at station C05003002 during the rainy season also exceeded the regulatory limits.

The presence of these metals may relate to the resuspension of sediment during maintenance dredging activities carried out on the León River, as well as sediment transported from where mining activities take place in the upper and middle basin of the river.

ICA Water Quality Index

IDEAM defines the ICA as a numeric value that uses categories to rate the water quality of surface currents by taking into account measurements of some of the water's physical and chemical variables. This gives a descriptive rating that facilitates the interpretation and identification of trends and decision-making regarding the body of water being studied[92].

The water quality index at station C050030156 on the León River was calculated using the virtual tool provided by the Water Research Center[93] and based on data regarding dissolved oxygen, pH, BOD, nitrates, orthophosphates and turbidity. The results given correspond to medium quality water in the rainy season and water of good quality in the dry season (see Table 5.27). Figure 5.64 shows graphical analysis of the classification of the water quality.

However, the index was not calculated with all the parameters, due to the high concentrations present, to some data being unavailable and to some measurement units at the station not coinciding with the units the method employs to calculate the index. For example, the index requires that fecal coliforms be measured in colony forming units (CFU/100ml) whereas the REDCAM stations record data determined using the most probable number method (NMP).

[92] INSTITUTE OF HYDROLOGY, METEOROLOGY AND ENVIRONMENTAL STUDIES (IDEAM). (Methodological water quality indicator sheet) (Version 1,00). System of Colombian environmental indicators- indicators of surface water quality. 10 p.

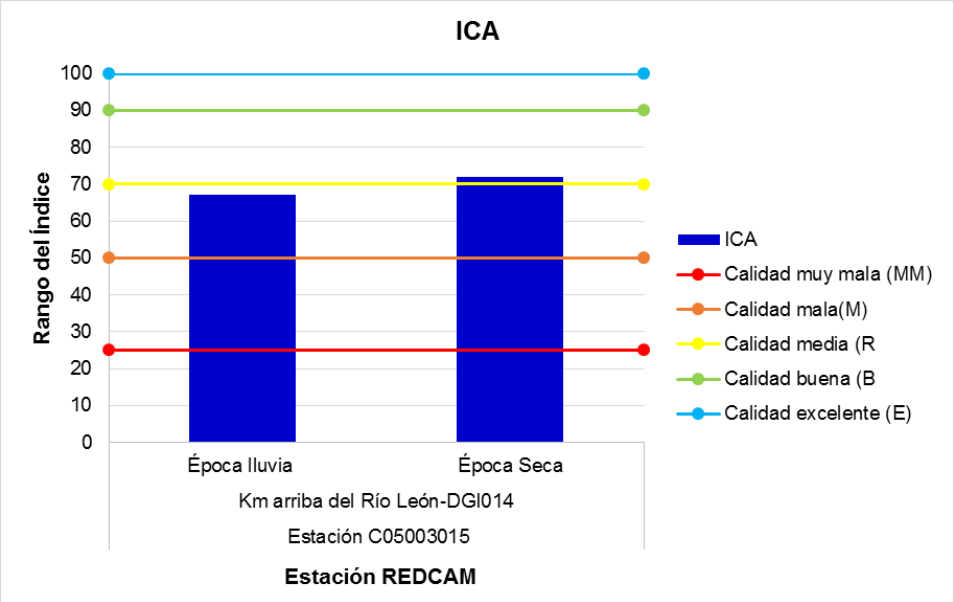
[93] Oram, B. (2014). Calculating NSF Water Quality Index. Retrieved October 2, 2015, from http://www.water-research.net/index.php/water-treatment/water-monitoring/monitoring-the-quality-of-surfacewaters

Table 5.27 ICA Results

Station C05003015	
1km upstream of the estuary of the León River - DGI014	
Rainy period	**Dry period**
67	**72**
Medium quality	Good quality

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

ICA



Very poor quality
Poor quality
Average quality
Good quality
Excellent quality

Rainy season Dry season
1km upstream from the León River- DGI014
Station C05003015
REDCAM station

Figure 5.64 ICA Water Quality Index- rainy and dry season
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

❖ ICAM Sea and Coastal Water Quality Index

The data recorded by REDCAM stations in the Gulf of Urabá were used to produce a qualitative description of the water quality in the area. This enabled it to be determined that the water of worst quality was found at the stations that are closest to the estuary of the León River, while the Bahía Colombia station inside the Gulf gave results showing optimum/adequate quality water. (see Table 5.28).

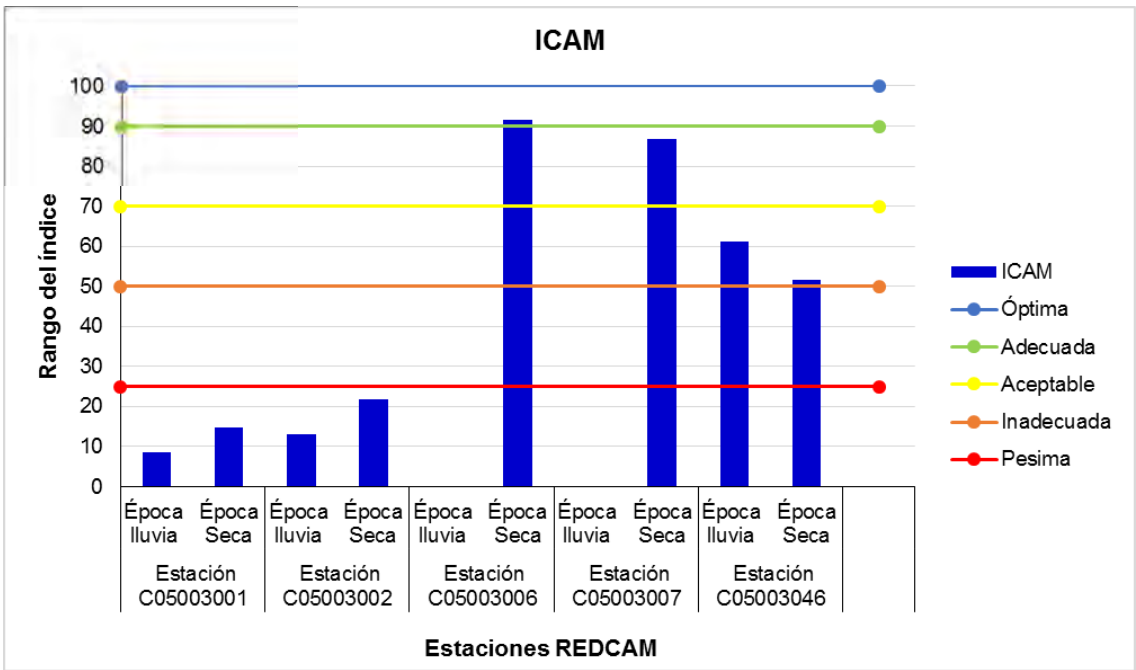
Table 5.28 ICAM Results

Index	Station C05003001		Station C05003002		Station C05003006	Station C05003007	Station C05003046	
	Rainy season	Dry season	Rainy season	Dry season	Dry season	Dry season	Rainy season	Dry season
ICAM Value	8.6	14.68	13.04	21.71	91.67	86.91	61.15	51.7
Indicator	Very poor	Very poor	Very poor	Very poor	Optimum	Adequate	Acceptable	Acceptable

Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

Figure 5.65 shows a graphical depiction of the results obtained when evaluating the quality of sea water at the various stations during the rainy and dry seasons.

ICAM



ICAM
Optimum
Adequate
Acceptable
Inadequate
Very poor

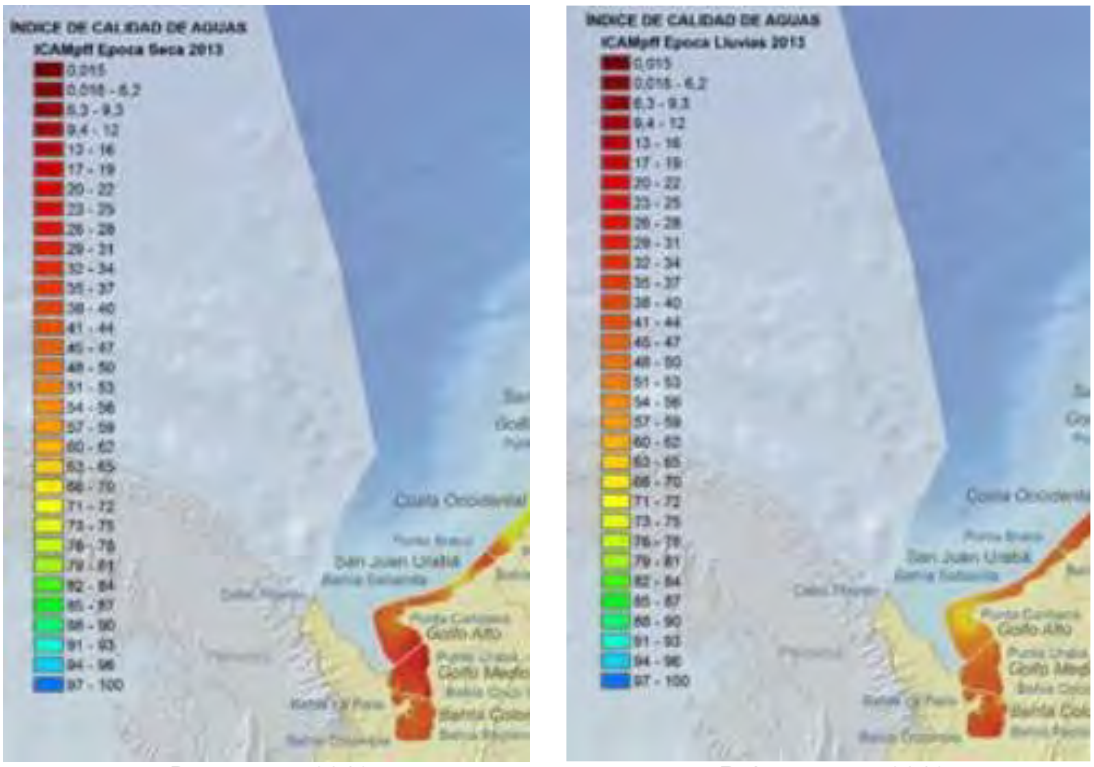
Época lluvia = rainy season
Época seca = dry season
Estación = station

REDCAM stations

Figure 5.65 Index of Sea and Coastal Water Quality- rainy and dry seasons
Source: Produced by *Aqua & Terra Consultores Asociados S.A.S*, 2015 with REDCAM information

According to the data presented in the Diagnosis and Evaluation of the Quality of Sea and Coastal Waters in the Colombian Caribbean and Pacific[94] (published by INVEMAR in March 2015), in general terms water quality in the Gulf of Urabá tends to be of unsuitable quality in the majority of sectors, with a higher tendency to be very poor quality water. In some areas, particularly the outer reaches of the Gulf, water of acceptable quality can be found during the rainy season (see Figure 5.66). The above is a reflection of the high pressure of human activities that the Gulf of Urabá is subject to, either directly or indirectly by means of pollutants that are transported there by the main rivers (Atrato, León, Leoncito, and Carepa, among others) that empty into the Gulf.

[94] VIAS-AGUAS, L.J., K. IBARRA, J. SANCHEZ, M. MARTINEZ, Y. NIETO, Y. MORENO, I. CUADRADO, P. OBANDO, O. GARCES, D. SANCHEZ, M. VILLARRAGA Y O.SIERRA. 2015. *(*Diagnosis and evaluation of the quality of sea and coastal water in the Colombian Caribbean and Pacific). From No.4 of a series of periodical INVEMAR publications (2015). Monitoring Network for the Conservation and Protection of the Marine and Coastal Waters of Colombia (REDCAM). Technical report 2014. INVEMAR. Santa Marta, 320 p.



Dry season 2013 Rainy season 2013

Figure 5.66 ICAM Index of Marine and Coastal Water Quality in the Gulf of Urabá

Source: INVEMAR, 2015

- *Quality of Inland Sediment*

The quality of the sediment of the inland depths was monitored at two stations located on the León River (downstream from its confluence with the Nueva Colonia canal, and downstream from the bridge that will be built over the river) on July 7th, 2015 at the coordinates shown in Table 5.14 and Figure 5.37.

- Results obtained on the quality of inland water

The physicochemical parameters evaluated in order to characterize the inland sediment correspond to those established in the reference terms for producing

Environmental Impact Studies for projects to construct, extend and operate major maritime ports (M-M-INA-05)[95].

The results of the parameters measured in laboratory are shown below:

Table 5.29 Results of Physicochemical Parameters – Inland Sediment

Parameter	Results	
	A1	A2
Fats and oils, mg/Kg	24	10
Total hydrocarbons, mg/kg	16	9
Copper, mg Cu/kg	6.90	7.20
Chromium, mg Cr/kg	6.3	4.8
Nickel, mg Ni/Kg	<0.0059	<0.0059
Zinc, mg Zn/kg	<0.1621	<0.1621
Phenols, mg/Kg	<0.01	<0.01

Source: *SGS Colombia S.A.S* (July 2015)

- Analysis of Inland Sediment Results

Analysis is provided below of the results of the physicochemical values obtained in laboratory for stations A1 and A2, situated on the León River, and they are compared with the limits established by the "*Canadian Sediment Quality Guidelines for the Protection of Aquatic Life"* for the parameters where a reference value is specified.

The limits established by the guide are:

ISQG (*Interim Sediment Quality Guidelines*): Refers to the interim sediment quality standard, which represents the concentration under which adverse biological effects can rarely be expected to occur.

PEL (*Probable effect levels*): This refers to the probable effect level, which determines the level above which adverse biological effects are expected to occur frequently, more than 50% of the adverse effects occur.

These values define three (3) chemical concentration ranges: the minimum effect range, within which adverse effects rarely occur (less than 25% of adverse effects under the ISQG); the possible effect range, within which adverse effects occasionally

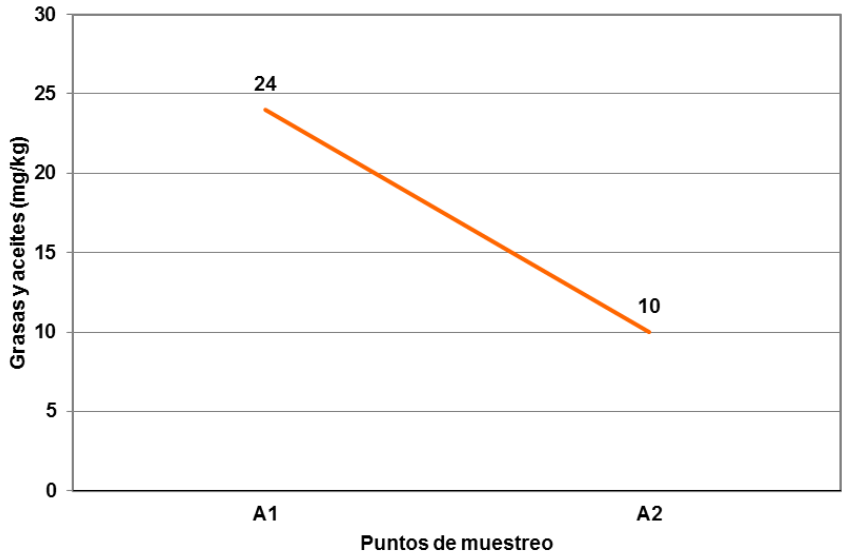
[95] COLOMBIA. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT MINISTRY. Resolution 0112 (January 28th, 2015). Adopting reference terms for producing Environmental Impact Studies, required for processing environmental licenses for projects to construct or extend and operate major maritime ports. Bogotá D.C., 2015. 103 p.

occur; and the probably effect range, within which adverse biological effects occur frequently (more than 50% of the adverse effects occur over the PEL)[96].

❖ Fats and Oils

The reported concentrations of fats and oils were 24mg/kg at station A1 and 10mg/kg at station A2, linked to the human activities that take place on the banks of the watercourse (see Figure 5.67).

The Canadian Sediment Quality Guidelines for the Protection of Aquatic Life establish no reference criteria for this parameter.



Fats and oils mg/kg **Sampling sites**

Figure 5.67 Amounts of fats and oils in inland sediment
Source: *SGS Colombia S.A.S* (July 2015)

❖ Total Hydrocarbons

The term “total hydrocarbons” is used to describe a large family, made up of several hundred chemical compounds that originate from crude oil. As a result of the varied origins of the hydrocarbons present in sediment, their presence is normally used as

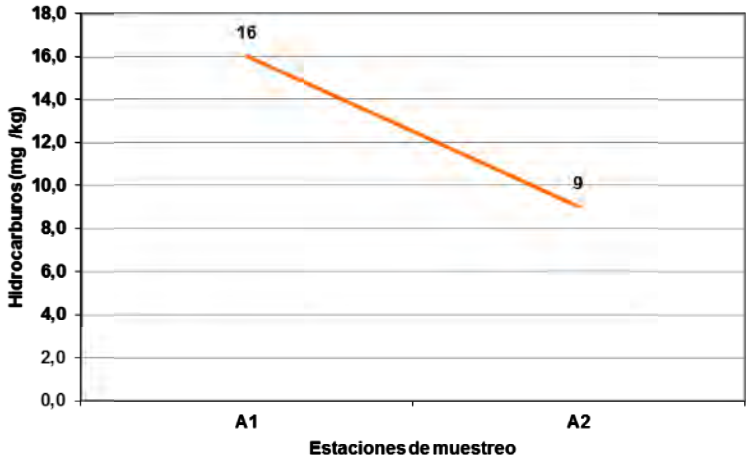
[96] *FUNDACIÓN CHILE*. (Hydrocarbon spill project, Blanca Choja and Maní streams, proposed selection of international soil/sediment reference values). Chile, 2013 [online] http://www. snifa.sma.gob.cl/ [Accessed September 25th, 2015]

a characteristic "marker" of different origins, and the definition of composition relationships between specific constituents of oil to distinguish between petrogenic and biogenic sources[97].

According to Saravia[98], a concentration of total hydrocarbons of ≤ 10 µg/g is considered to be uncontaminated. Concentrations of hydrocarbons within the <10 - 100 µg/g range is classified as slightly to moderately contaminated. Finally, if levels of total hydrocarbons reach ≥ 100 µg/g the system is highly contaminated.

With this classification in mind, the concentrations of hydrocarbons reported in the sediment of the León River are relatively low. This is due to concentrations of 16mg/kg being found at station A1 (classified as slight to moderate) and results of 9mg/kg for station A2, leading to it being categorized as uncontaminated (see Figure 5.68).

With regards to the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, no reference criteria are established for this parameter.



Hydrocarbons (mg/kg) **Sampling Stations**

Figure 5.68 Amounts of total hydrocarbons in inland sediment
Source: *SGS Colombia S.A.S* (July 2015)

[97] COMPANIONI, D., NUÑEZ, A., CORA, M., ROSABLA, M., GONZÁLEZ, L., MARBOT, R. et al. (Anthropogenic hydrocarbons in sediment of the northeast coast of La Habana EY, 2011) [online] http://www.scielo.org.mx/scielo.php [Accessed September 24th, 2015].

[98] SARAVIA, Ana., RODRIGUEZ, Daniela., PACHECO, Oscar., PIEDRA, Oscar. (Evaluation of hydrocarbon levels in marine sediment, and their potential origin and effects on aquiculture activities between Punta Morales and Costa de Pájaros in the Gulf of Nicoya). In: Geographical Magazine of Central America. Nº 53, ISSN 1011-48X, July-December 2014 p. 113-134

Sediment plays an important role in the identification, monitoring and distribution of contaminant metals. Unbalanced concentrations of these metals can lead to impoverished biological productivity; low or very high concentrations of metals can result in toxic activity. While some metals play an important role in the growth, development and reproduction of living beings, in many cases their presence can have a negative effect, even in low concentrations[99]. The results obtained for the metals evaluated are provided below:

- **Copper**

This metal is of great importance due to its easy absorption into solid particles in suspension and rapid assimilation into sediment[100]. Concentrations of copper in water can affect photosynthesis and the growth of algae, and can have an effect on the early developmental stages of marine organisms (eggs, larvae etc.), or even bring about their death[101].

The reported concentrations show a slight difference in metal content at station A2 (7.20 mg/kg) compared with station A1 (6.90 mg/kg). See Figure 5.69.

[99] ALAMA, M. T. (Comparison of the concentrations of trace elements in farmed and wild carp (Cyprinus carpio) in Kasumigaura Lake). 2002.
[100] MANTOURA, R., DICKSON, A., y RILEY, J. The complexation of metals with humic materials in natural water. 1978, Estuary and Coastal Marine Science 6, 387-408.
[101] ZAMUDIO, Rosa. (Heavy metals in marine sediment in the Veracruz National Park Reef System). 2014, Mexico.

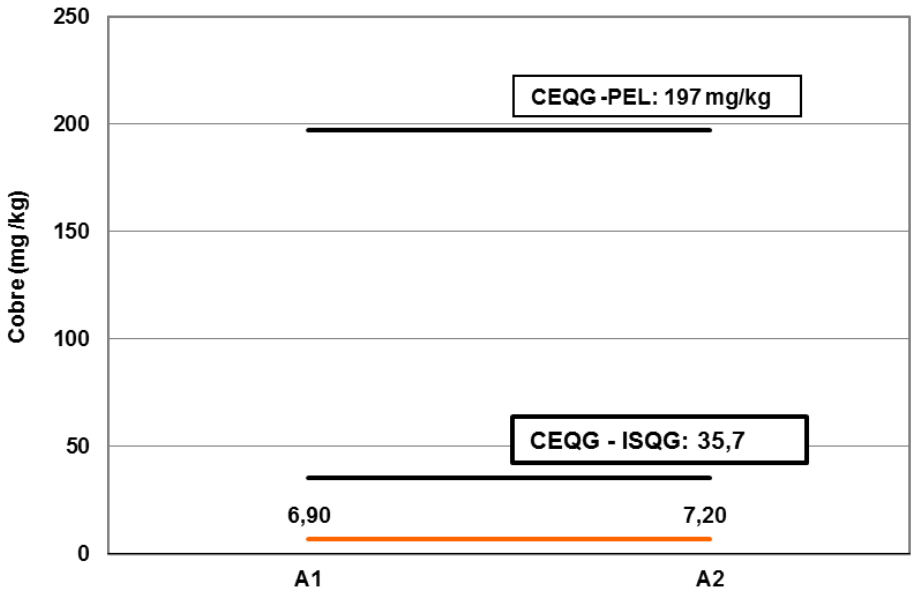


Figure 5.69 Traces of copper in inland sediment
Source: *SGS Colombia S.A.S* (July 2015)

In terms of compliance with the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, both the PEL and ISQG concentrations are below standard. Consequently, it can be inferred that such concentrations are not expected to lead to adverse biological effects on the aquatic biota.

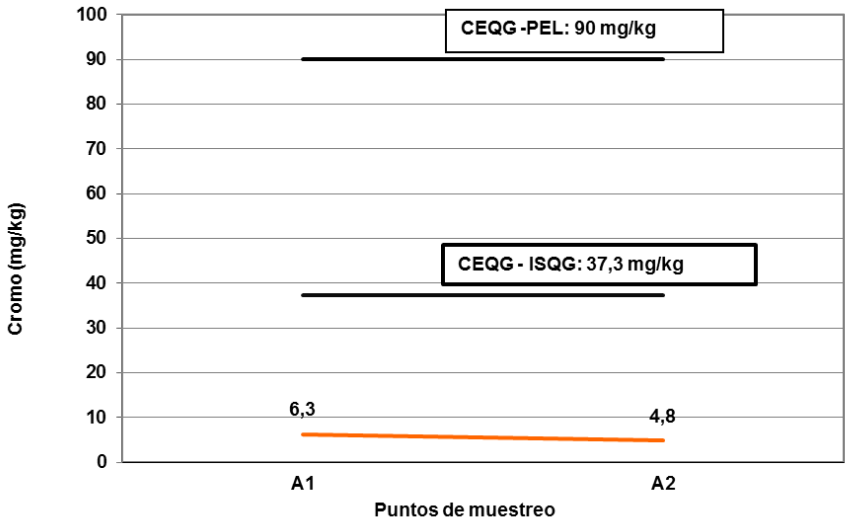
- **Cromo**

El cobre es un metal que ocurre naturalmente en el ambiente en rocas, el suelo, el agua y el aire y es un elemento esencial para los organismos vivos. A nivel de sedimentos, su análisis tiene gran importancia, debido a que tiene mucha facilidad en adsorberse sobre las partículas sólidas en suspensión e incorporarse rápidamente al sedimento. La concentración por cobre en el agua puede afectar la fotosíntesis y desarrollo de las algas, así como las primeras etapas de desarrollo de los organismos marinos (huevos, larvas, etc.), e incluso provocar la muerte de los mismos[102].

[102] ZAMUDIO, Rosa. (Heavy metals in marine sediment in the Veracruz National Park Reef System). 2014, Mexico.

The concentrations recorded show higher levels of chromium at station A1 (with 6.3mg/kg) in comparison with results of 4.8mg/kg observed at station A2 (see Figure 5.70.

With regards to regulatory compliance, both concentrations can be said to be below the ISQG (37.3mg/kg) and PEL (90mg/kg) standards, according to the comparison made with the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Therefore, it can be inferred that the concentrations observed do not interfere with the metabolic activities of aquatic organisms.



Chromium (mg/kg) **Sampling sites**

Figure 5.70 Traces of chromium in inland sediment

Source: *SGS Colombia S.A.S* (July 2015)

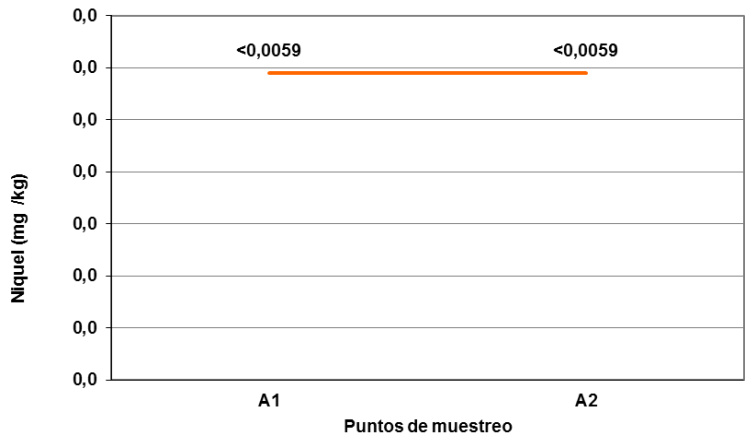
❖ Nickel

Nickel is usually present in bodies of water in mainly soluble form, although it can occasionally form complexes that are not particularly stable. Similarly, a certain amount of nickel can remain absorbed into solid or sediment particles[103].

The concentrations reported at both sampling stations were below the detection limit of the method employed by the laboratory (<0.0059 mg/L), suggesting that there were no different patterns of behavior between both points, and that the presence of zinc was nearly zero (Figure 5.71). With regards to the Canadian Sediment Quality

[103] DOMENECH, X. (Chemistry of the hydrosphere: origin and destination of contaminants). Madrid, 1995.

Guidelines for the Protection of Aquatic Life, no reference criteria are established for this parameter.



Nickel (mg/kg) **Sampling sites**

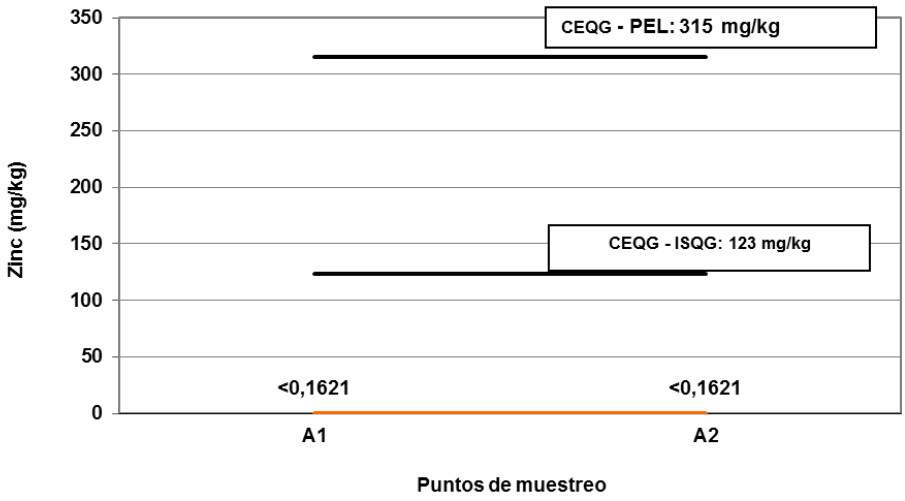
Figure 5.71 Traces of zinc in inland sediment
Source: *SGS Colombia S.A.S* (July 2015)

❖ Zinc

This element is widely present in nature, is associated with sulphides of other metals (Fe, Cu, Cd, Pb) and can also be found as pure zinc sulphide in the blende. Its presence in both surface and underground natural water is unusual; it can be found in inorganic, ionic or colloidal form and its most frequent chemical species are Zn^{2+}, $Zn(OH)^{+}$ y $ZnCl^{-3}$. Zinc's poorly soluble compounds (hydroxides and carbonates) are capable of being substantially absorbed into sediment and mud on the beds of watercourses[104].

As with the analysis of nickel, the concentrations recorded (<0.1621 mg/L) were below the detection limit of the method utilized by the laboratory (see Figure 5.72).

[104] MARÍN, R. *Fisicoquímica y microbiología de los medios acuáticos* (Physicochemistry and microbiology of aquatic environments). Madrid: *Ediciones dias de Santos S.A.*, 2003.



Zinc (mg/kg) Sampling sites

Figure 5.72 Traces of zinc in inland sediment
Source: *SGS Colombia S.A.S* (July 2015)

❖ Phenols

The contamination of the marine ecosystem by phenols is primarily caused by the discharge of waste water, more so than by the natural decomposition of organic matter. Particular causes include industrial waters derived from coal processing, refineries, pulp and timber production, dying operations and the manufacture of pesticides, plastics and resins[105].

In addition to having an effect on organisms, phenols pose an aesthetic problem for aquatic ecosystems given that they can alter the color and odor of water. The coloration of water can attain tones that range from yellow to brown, a situation caused by the presence of some substituted phenols, or by the products of the oxidation process of the family being studied[106].

The concentrations of phenols at monitoring stations A1 and A2 were at the detection limit of the analytical technique, confirming that sediment originating in the León River does not show significant concentrations of this compound (see Figure 5.73).

[105] CAMPOS, C. *Compuestos fenólicos y el medio ambiente* (Phenolic compounds and the environment). Cuba, 2009
[106] Ibid.

With regards to the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, no reference criteria are established for this parameter.

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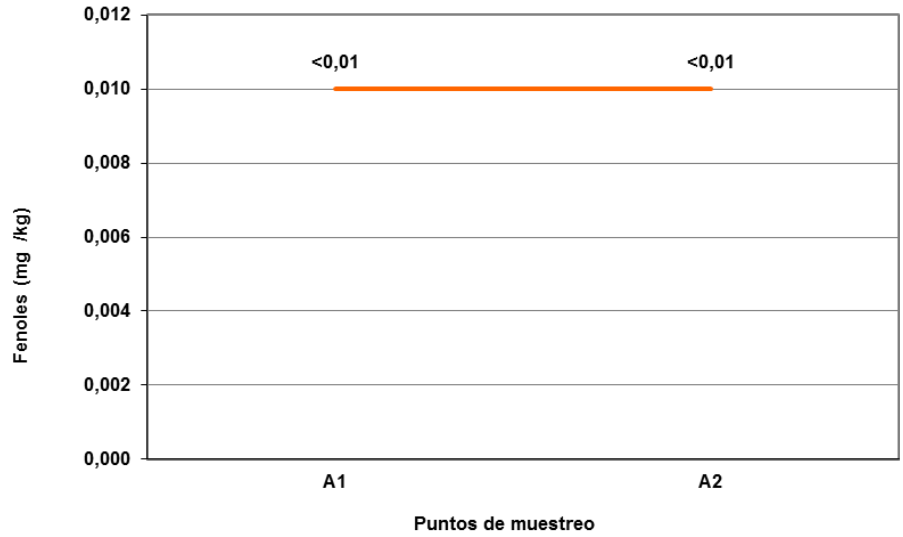


Phenols (mg/kg) Sampling sites

Figure 5.73 Traces of phenols in inland sediment

Source: *SGS Colombia S.A.S* (July 2015)

- Comparison with national and international standards

Given that Colombian regulations set no limits in terms of inland sediment, the results obtained were compared with the limits established by the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life[107]. These guidelines were referred to in previous graphs and are summarized in Table 5.30 below:

Table 5.30 Comparison between the results obtained and regulations

Parameter	Results		Canadian Guidelines for the Protection of Aquatic Life		Compliance
	A1	A2	ISQG	PEL	
Copper, mg Cu/kg	6.90	7.20	35.7	197	In compliance

[107] CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT – CCME. Canadian water quality guidelines for the protection of aquatic life: Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving Numerical Water Quality Objectives. In: Canadian environmental quality guidelines, 1999. [online] < http://ceqg-rcqe.ccme.ca/en/index.html> [Accessed September 11th, 2015]

Chromium, mg Cr/kg	6.3	4.8	37.3	90	In compliance
Zinc, mg Zn/kg	<0.1621	<0.1621	123	315	In compliance

Source: *Canadian Sediment Quality Guidelines for the Protection of Aquatic Life"*[108]
ISQG: Interim Sediment Quality Guideline
PEL: Probable effect level

All of the evaluated parameters that had a reference value for comparison were shown to be below the ISQG (interim sediment quality guideline) and the PEL (probable effect level). Therefore, at these concentrations adverse biological effects do not frequently occur.

5.1.7 Water Uses

- *Current Uses and Users*

The main population centers in the region are in the basin of the León River, making it the most developed area. The river's principal tributaries are found on its right bank, with the most important being the Villarteaga, Juradó, Cuapá, Chigorodó, Carepa and Zungo[109]. Although the basin of the León River still has no management scheme (POMCA), CORPOURABÁ Resolution No. 200-03-20-99-1341-2014 declared it as under management to enable suitable planning to be carried out with regards to the use of the soil, water, flora and fauna.

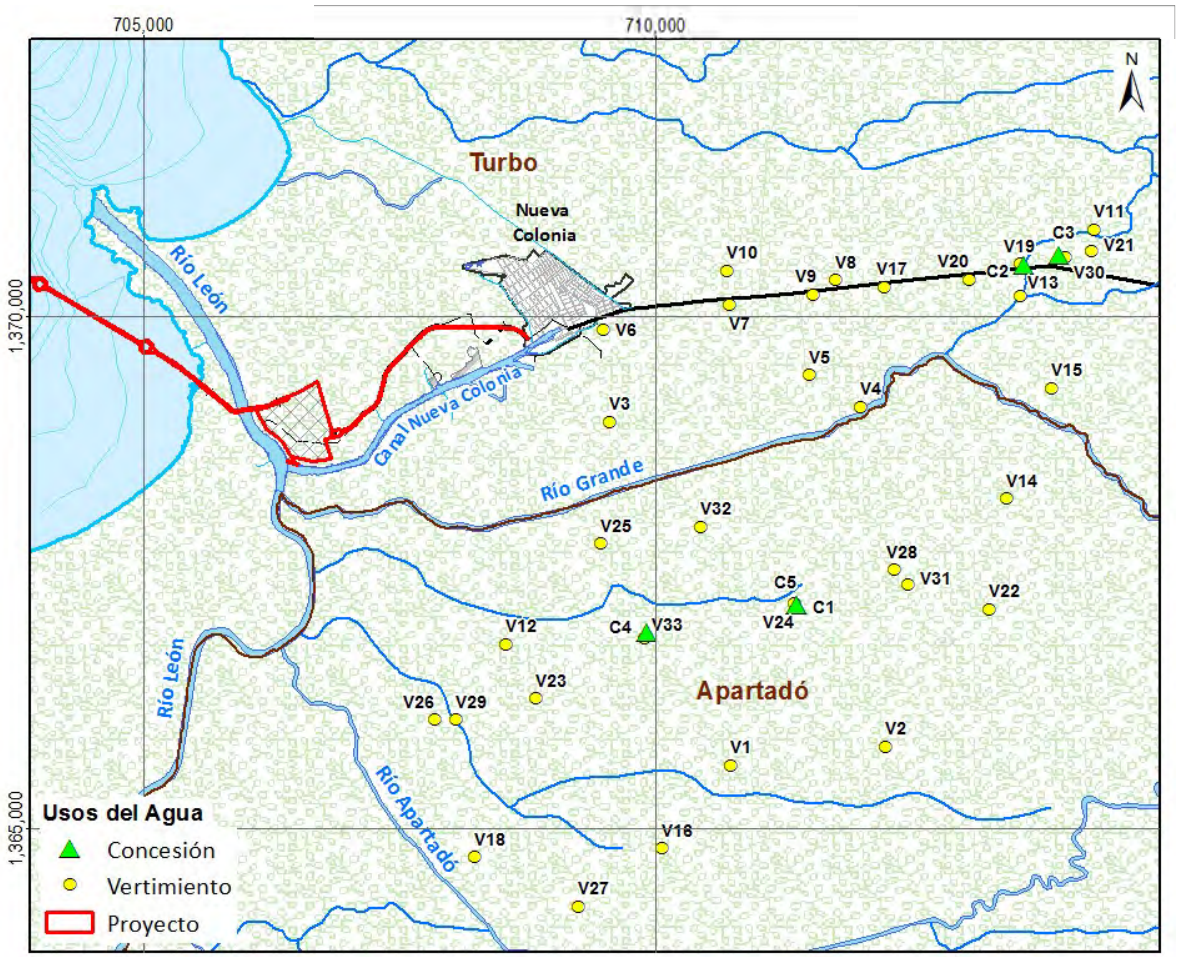
The León River has been used as a waterway by banana companies, which transport the fruit for export on barges from the upstream terminals to the ship anchorage areas in Bahía Colombia[110]. The river is also the watercourse that receives the water from the sewage systems of municipalities such as Apartadó, Chigorodó, Carepa and Mutatá, in addition to water from run-off and the drainage systems of the banana companies throughout its basin.

After the confluence of the Carepa tributary, most of uses are very highly restricted on the León River, particularly the use of water for agricultural purposes due to high chloride content that can cause soil salinization. The water in the section between Barranquillita and the confluence of the River Chigorodó poses risks for human and recreational consumption, albeit lower than those present in the lower part of the

[108] Ibid.
[109] NATIONAL PLANNING DEPARTMENT. (Strategic plan for the Urabá-Darién region. First phase: constructing inputs for the process in the region). Medellin, 2006. 154 p.
[110] NATIONAL UNIVERSITY OF COLOMBIA, Oceanic research group. (Analysis of alternatives to mitigate sediment issues in the estuary of the River León). Medellin, 2010. 113 p.

León River. There are limiting factors of dissolved oxygen between the mouths of the River Carepa and the Carepita channel[111].

No concessions or discharging of water authorized by Corpourabá[112] were identified in the project's area of influence. However, those points located within a 5km radius of the project's abiotic component that are also tributaries of the León River watershed were taken as references (see Figure 5.74 , Table 5.31 and Table 5.32.



Water Uses
Concession
Discharge
Project

[111] *PUERTO BAHÍA COLOMBIA DE URABA S.A.* AND *ARAÚJO IBARRA & ASOCIADOS S.A.* (Environmental impact study for the construction and operation of a bulk solids port terminal). Turbo. 2010. 428 p.
[112] CORPOURABÁ, Database, 2013.

Figure 5.74 Water points: surface concessions and water discharging authorized by Corpourabá[113]

Source: *Aqua & Terra Consultores Asociados S.A.S (*2015) with CORPOURABÁ information (2013)[114]

Table 5.31 Record of Concessions

ID	Concession User	Catch-ment Area	Collection type	Water Use	MAGNA-SIRGAS Planar Coordinates, Origin BOGOTÁ	
					EAST	NORTH
C1	C.I. CONSERBA S.A.	Turbo	Surface	Domestic & Agricultural	711.375,8	1.367.185,5
C2	C.I. UNIBAN S.A.	Turbo	Surface	Domestic & Agricultural	713.598,1	1.370.505,2
C3	C.I. UNIBAN S.A.	Turbo	Surface	Agriculture	713.929,8	1.370.601,5
C4	C.I. UNIBAN S.A.	Apartadó	Surface	Agriculture	709.917,6	1.366.917,9
C5	N/A	Tonusco	Surface	Irrigation	711.375,8	1.367.185,5

Source: CORPOURABÁ, 2013[115]

Table 5.32 Record of Discharge

ID	User	Municipality	Location	MAGNA-SIRGAS Planar Coordinates, Origin BOGOTÁ	
				ESTE	NORTE
V1	C.I. Banacol S.A.	Apartadó	Comunal La Cordialidad	710.734,3	1.364.724,2
V2	C.I. Banacol S.A.	Apartadó	Comunal La Cordialidad	712.237,9	1.364.922,2
V3	C.I. Banacol S.A.	Turbo	Nueva Colonia	709.544,3	1.368.065,6
V4	C.I. Banacol S.A.	Turbo	Nueva Colonia	711.995,0	1.368.224,5
V5	C.I. Banacol S.A.	Turbo	Nueva Colonia	711.494,1	1.368.534,3
V6	C.I. Banafrut S.A.	Turbo	Nueva Colonia	709.485,6	1.368.962,6
V7	C.I. Banafrut S.A.	Turbo	Nueva Colonia	710.713,5	1.369.212,6
V8	C.I. Banafrut S.A.	Turbo	Nueva Colonia	711.757,5	1.369.462,4
V9	C.I. Banafrut S.A.	Turbo	Nueva Colonia	711.529,7	1.369.317,8
V10	C.I. Banafrut S.A.	Turbo	Nueva Colonia	710.694,2	1.369.544,3

[113] CORPOURABÁ, Database, 2013.
[114] Ibid.

[115] Ibid.

ID	User	Municipality	Location	MAGNA-SIRGAS Planar Coordinates, Origin BOGOTÁ	
				ESTE	NORTE
V11	C.I. Conserva S.A.	Turbo	Comunal La Suerte	714.268,6	1.369.974,8
V12	C.I. Conserva S.A.	Apartadó	Comunal La Cordialidad	708.540,1	1.365.892,7
V13	C.I. Proban S.A.	Turbo	Palos Blancos	713.550,1	1.369.313,5
V14	C.I. Proban S.A.	Apartadó	Palos Blancos	713.427,4	1.367.344,2
V15	C.I. Proban S.A.	Turbo	Nueva Colonia	713.860,3	1.368.426,0
V16	C.I. Tropical S.A.	Apartadó	Comunal La Cordialidad	710.057,6	1.363.912,5
V17	C.I. Uniban S.A.	Turbo	Nueva Colonia	712.229,2	1.369.395,2
V18	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	708.229,5	1.363.812,6
V19	C.I. Uniban S.A.	Turbo	Nueva Colonia	713.555,1	1.369.630,0
V20	C.I. Uniban S.A.	Turbo	Nueva Colonia	713.054,5	1.369.479,0
V21	C.I. Uniban S.A.	Turbo	Comunal La Suerte	714.254,9	1.369.759,7
V22	C.I. Uniban S.A.	Apartadó	Palos Blancos	713.252,0	1.366.262,6
V23	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	708.834,2	1.365.361,5
V24	C.I. Uniban S.A.	Apartadó	Palos Blancos	711.351,4	1.366.313,0
V25	C.I. Uniban S.A.	Apartadó	Palos Blancos	709.460,1	1.366.876,6
V26	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	707.845,5	1.365.148,7
V27	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	709.244,5	1.363.340,4
V28	C.I. Uniban S.A.	Apartadó	Palos Blancos	712.325,4	1.366.642,7
V29	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	708.050,9	1.365.148,9
V30	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	713.994,0	1.369.704,1
V31	C.I. Uniban S.A.	Apartadó	Palos Blancos	712.459,4	1.366.504,6
V32	C.I. Uniban S.A.	Apartadó	Palos Blancos	710.436,2	1.367.049,5
V33	C.I. Uniban S.A.	Apartadó	Comunal La Cordialidad	709.883,5	1.365.952,3

Source: CORPOURABÁ, 2013[116]

- *Reference Indicators*

The National Water Study was taken as reference information (ENA 2014)[117] and defines three hierarchical levels of spatial analysis: 1) the five hydrographic areas

[116] Ibid.
[117] INSTITUTE OF HYDROLOGY, METEOROLOGY AND ENVIRONMENTAL STUDIES (IDEAM), ENVIRONMENT, HOUSING AND TERRITORIAL DEVELOPMENT MINISTRY (MAVDT). National Water Study. Bogota, 2014. 493 p. ISBN: 978-958-8067-70-4.

associated with the country's principal watersheds: Caribbean, Magdalena-Cauca, Orinoco, Pacific and Amazon; 2) the hydrographic zones and 3) the hydrographic sub-areas that make up a total of 316 hydrographic areas. The design of these areas is taken as a basis for describing the supply of surface water and the development of the various hydric indicators.

Hydrographic subareas are defined as hydric subsystems with uniform relief and drainage characteristics, made up of basins from the high, middle and low points of a hydrographic zone that capture water and sediment from tributaries of different types, such as springs, streams, creeks and rivers. Taking the above into account, the area of study is in the León River hydrographic subarea. In an average year this subarea has a total supply of 4.526 billion cubic meters (Mm^3), which drops to 1.488 billion cubic meters (Mm^3) in dry years.

Of the indicators used by the National Water Study[118], the following indexes were taken into account for this study: the Water Use Index (WUI), which measures the amount of water used by the various sectorial users; the Water Retention and Regulation Index (WRR), which evaluates the capacity of catchment areas to maintain a flow regime and retain moisture, and the Vulnerability to Water Shortage Index (VWS), which is defined as the water system's degree of fragility in maintaining the supply of water.

For the León River subarea, according to the Water Use Index the National Water Study[119] concluded that the pressure of demand is low compared with the supply of an average year, and moderate in comparison with a dry year's supply. The Water Retention and Regulation Index showed that the watershed is of low regulation, and the Vulnerability to Water Shortage Index gave medium results. The latter means that when faced with threats such as prolonged periods of low water levels or events like El Niño, a risk of water shortage could occur due to flow reductions of between 10% and 55% (see Table 5.33).

[118] Ibid.
[119] Ibid.

Table 5.33 Hydric indicators for the León River hydrographic subarea for average and dry hydrological conditions

Hydrographic subarea	Area (km2)	Available supply		Water Use Index				Regulation Index		Vulnerability Index
		Average supply (MCM)	Dry supply (MCM)	WUI average year	WUI Category	WUI dry year	WUI Category	Index	Category	Average year
León River	2278	2940	967	4.74	Low	14.41	Moderate	61.40%	Low	Medium

MCM: Million cubic metres

Source: National Water Study, 2014[120]

With regards to the chemical and organic load contaminants (COD and BOD), the León River is under high to very high pressure (See Table 5.34). In dry years these conditions are exacerbated, causing the effects of extreme phenomena such as El Niño to become particularly severe[121].

Table 5.34 Contaminating loads of BOD, COD and COD-BOD

Hydrographic area	Hydrographic zone	Hydrographic subarea	BOD (t/year)	COD (t/year)	COD-BOD (t/year)
Caribbean	Caribbean coast	León River	4171	7847	3676

Source: National Water Study, 2014[122]

5.1.8 Hydrogeology

In the banana-growing region, underground water constitutes a cornerstone for the supply of water to the population and for the region's economy and productivity. It also acts as supply source for various communities located in the rural and urban headwaters of the Carepa, Turbo and Chigorodó municipalities. Direct and indirect employment is dependent on the use of underground water, making this resource a driving force for the region's economic development[123].

In the Urabá region, this resource has been widely used in agricultural production for a number of decades, particularly in the banana-growing sector. However, with

[120] Ibid.
[121] Ibid
[122] Ibid.
[123] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ), NATIONAL UNIVERSITY OF COLOMBIA (UNAL). *Hidrogeología del acuífero del Eje Bananero de Urabá* (Hydrogeology of the aquifer in the banana-growing region of Urabá). 2010

the increased population and the scarcity of surface water, companies that provide drinking water have expressed an interest in making use of the water.

With a view to improving the management of this resource, CORPOURABA has performed studies with public and private organizations in order to discover as much as possible about the Gulf of Urabá aquifer, and to be able to produce the best characterization possible of it. However, the hydrogeological models obtained from these studies have been general in nature; deciphering the geological environment under the ground's surface is complex task that is often incorrectly interpreted. This is because the underground water environment is hidden from view, and the impressions given can be deceiving[124].

In this section, our interest lies in producing a conceptual hydrogeological model that can show the spatial distribution of the different aquifer bodies. This is done by interpreting geophysical records situated in the direct vicinity of the Bahía Colombia port terminal project area, in addition to historical records from exploratory campaigns previously carried out by Corpourabá, Colombia's National University and state and/or private entities. When done correctly, this enables the scale of the aquifers to be determined in terms of extension and depth, defining a baseline for quality monitoring and water conservation. The information will be presented using stratigraphic cross-sections, thematic shapes and longitudinal profiles.

- *Regional and Local Factors*

In order to permit explanation of the conceptual model of the aquifer related to the project, information and knowledge of the area's geological environment is required.

The geological information provided here will comprise a bibliographic summary which uses the 1995 INGEOMINAS evaluation of underground water in the Gulf of Urabá as a basis[125], as well as the geological study carried out by the ANH (2009)[126], information from recent public and private works and the information obtained from fieldwork.

[124] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). (Conceptual hydrogeological model of the Gulf of Urabá aquifer, produced based on interpretations of geological and geophysical information). 2013

[125] COLOMBIAN GEOLOGICAL SERVICE (SGC, previously INGEOMINAS). (Evaluation of underground water in the Urabá region of the Department of Antioquia). (unpublished). Report 2229,1995.

[126] NATIONAL HYDROCARBONS AGENCY (ANH) & NATIONAL UNIVERSITY OF COLOMBIA (UNAL). (Geological cartography project and structural modelling of the Urabá and Sinú-San Jacinto basins, based on interpretations of remote sensor images and seismic monitoring). 2009.

- Regional Hydrogeological Units

Two highly-differentiated tertiary units exist in the Urabá region of the department of Antioquia, unit T1 of marine origin and unit T2 of inland origin. However, in the northern region the Tertiary is almost entirely represented by unit T1[127].

INGEOMINAS (1995)[128] and Colombia's National University distinguish the geological units T2C, T2B, T2A, T1 and alluvial deposits. The regional hydrogeological units present in the area of study are described below.

❖ **Unit T2C**

This unit corresponds to the subunit above unit T2, and surfaces to the west of the western range of the Andes and towards the north as a narrow strip running south to north. It lies under unit Qal and above unit T2B, and its thickness varies between 5m and 70m between Turbo and Apartadó.

❖ **Unit T2B**

This unit corresponds to the middle subunit of unit T2 and surfaces towards the east of the area of influence. In terms of depth, it lies below unit T2C and above unit T2A. The group shows a thickness that varies between 20m and 190m with the maximum in the municipalities of Carepa y Chigorodó, where it constitutes the main core of the Chigorodó anticline.

❖ **Units T2A and T1**

These units correspond to the subunit below unit T2 and to unit T1 itself, and are classified as units of very low or zero relative hydrogeological importance.

❖ **Alluvial Plain Deposits**

This unit covers the flat part of the area of study (i.e. from the foothills of the Abibe mountains towards the west), and is the shallowest aquifer in the region with a maximum thickness of 30m. Its thickness in the area of influence varies between 6m and 30m according to geophysics and up to the depth of the mechanical explorations carried out.

[127] HAFFER, J. On the Geology of the Urabá and northern Choco report. 357 (typed). ECOPETROL. Bogotá, 1967. 105 p.
[128] COLOMBIAN GEOLOGICAL SERVICE (SGC, previously INGEOMINAS). 2005. Op. cit.

According to the monitoring performed on the Urabá network of wells, it can be inferred that the underground water flows in a north-westerly direction. This pattern changes when the region's irrigation systems enter into operation in the dry season.

The area of study is characterized by gentle to slightly undulating topography, with alluvial fans present in the foothills of the mountains caused by the rivers that rise to the east of the high regions. The main drainage basins adjacent to the area correspond to the catchment area of the León River, which takes a southeast to northeast course, later turning northwards to empty into the Gulf of Urabá.

- Hydrogeological units local to the area of influence

Two large hydrogeological units were identified in the project's area of influence and are described below. Their presence was determined by the behavior of underground water and by the primary data recorded from the exploratory campaigns[129].

❖ **Quaternary Alluvial Aquifers (QAA)**

There are at least two strips of the Quaternary that show a lithology of fine, medium and coarse sands, one within the first 40m to 50m and the other from 70m to 100m in the area of influence (see MOD_LA_PTO_ANT_20_Hidrogeologia).

The studies carried out in the Gulf of Urabá suggest that the thickness of the shallowest aquifer in the area is between 6m and 45m. It is subsequently interrupted or enclosed by a clay matrix that is high in plasticity and rigidity and may have created the second layer of aquifers. This second layer receives the discharge that comes from the foothills of the Abibe mountains and has access to the underlying layers of alluvial deposits due to several conditions, including the potential fracturing and changeability of the rock, the direction of the dip and the orientation of synclines and anticlines.

The conglomerate levels of the Tertiary aquifer match those of the Arenas Monas formation (T2C). It appears closer to the surface in the eastern parts of the area, without being detected in the area of influence.

[129] *PIO S.A.S., EDIFICA COLOMBIA LTDA*. (Basic and detailed engineering, purchasing and supply of materials, construction, assembly and launch of the work required for Phase 1 of the Puerto Antioquia port terminal located in the estuary of the River León, in the Gulf of Urabá in the Department of Antioquia). Geotechnical study for Conceptual Engineering, 2015.

The quality of the underground water of the aquifers in the area of influence fluctuates between slightly saline and brackish. Vasquez's study (2011[130]) mentions the existence of a single layer with salt water at a shallow depth, due to the movement of the salt wedge towards the interior of the inland area in the proximity of the Gulf of Urabá.

The aquifers have an estimated porosity of 0.34 and an effective porosity of 0.19. However, in accordance with the rate of deposition and the uniformity of the alluvial plain of the Quaternary, more investigation and testing are recommended towards the coastal area in order to better determine the actual extension of the aquifers.

- **Aquitards (Act)**

Based on the geological and lithostratigraphic profiles generated in previous studies, in addition to the profiles detected during direct exploration in the project area, the alluvial deposits and torrential alluvial deposits situated to the east of the area of influence are considered to be of low hydrogeological potential, where the passage of water is slower and there is little interconnection between areas with water content. (See MOD_LA_PTO_ANT_20_Hidrogeologia).

- Tectonics

The area of influence is situated in the middle of the interaction between two large tectonic blocks. To the west, the Panamá-Chocó block extends from the extreme north-west of the western range of the Andes to the Darién and San Blas mountains; the Andes block of the South American Plate is located to the east. The seam zone between both plates follows the Uramita fault, which is situated on the western flank of the western range of the Andes[131] (see Figure 5.75 and Figure 5.76).

The tectonics of the Urabá area is also associated with the dynamics that exist between blocks, which represent the geological events recorded on the plain, in the Abibe Mountains and the surrounding areas. They are an accurate reflection of the existing relief, as a response to compression, distension, transpression and transtension events[132].

[130] VÁSQUEZ, L. (Evaluation of hydrogeological information derived from the perforation of deep wells and vertical electrical soundings). 2011.
[131] PIO S.A.S., EDIFICA COLOMBIA LTDA (Geotechnical Study for Conceptual Engineering, 2015). Op. Cit.
[132] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ), NATIONAL UNIVERSITY OF COLOMBIA (UNAL). (Conceptual hydrogeological model of the Gulf of Urabá aquifer, produced based on interpretations of geological and geophysical information). 2010. 50 p.

The scale and extension of the aquifers is controlled by the presence of structural alignments, tectonic dislocations and regional structures in the area, such as the Uramita Fault and broad synclines.

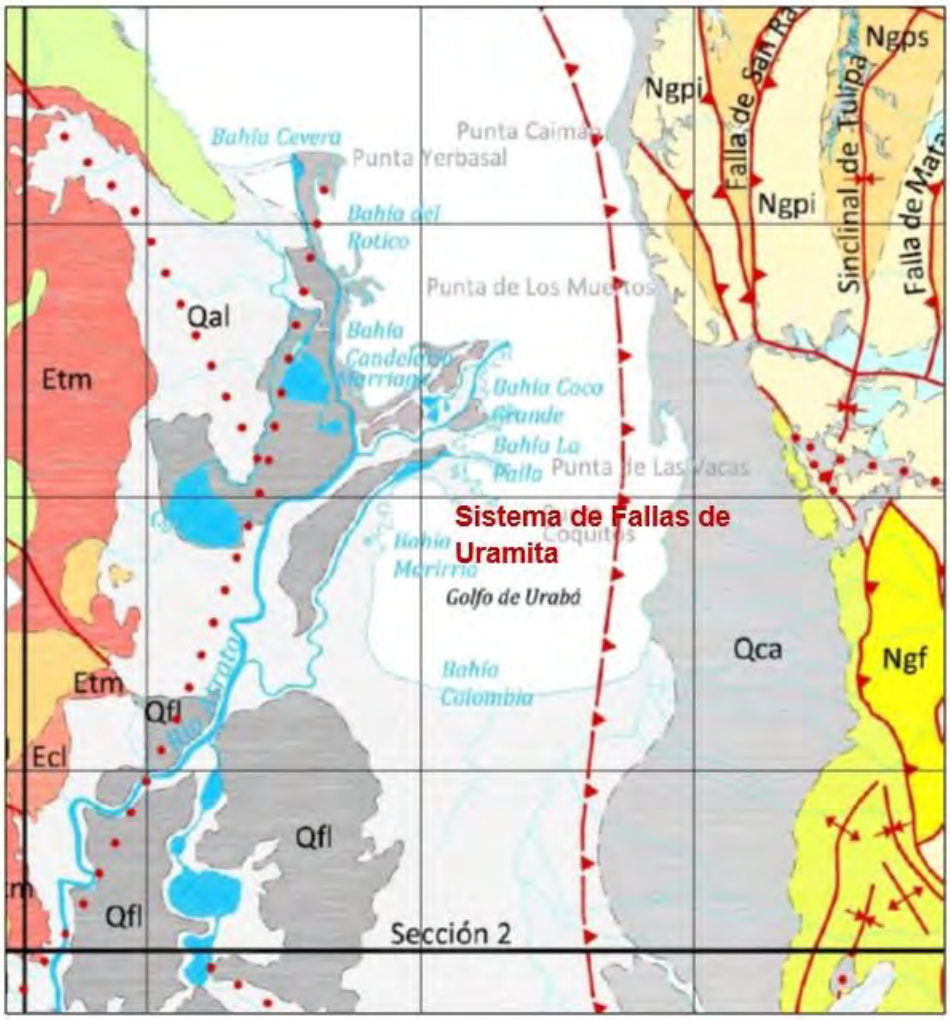


Figure 5.75 Geological map created based on plates 58, 59, 60, 68, 69, 70, 79B, 79, 80, 89, 90, 91,101,102 and 103 at 1:100000 scale.
Source: INGEOMINAS 1999 and 2005, in *PIO S.A.S*, 2015[133]

[133] PIO S.A.S., EDIFICA COLOMBIA LTDA, 2015. Op. cit.

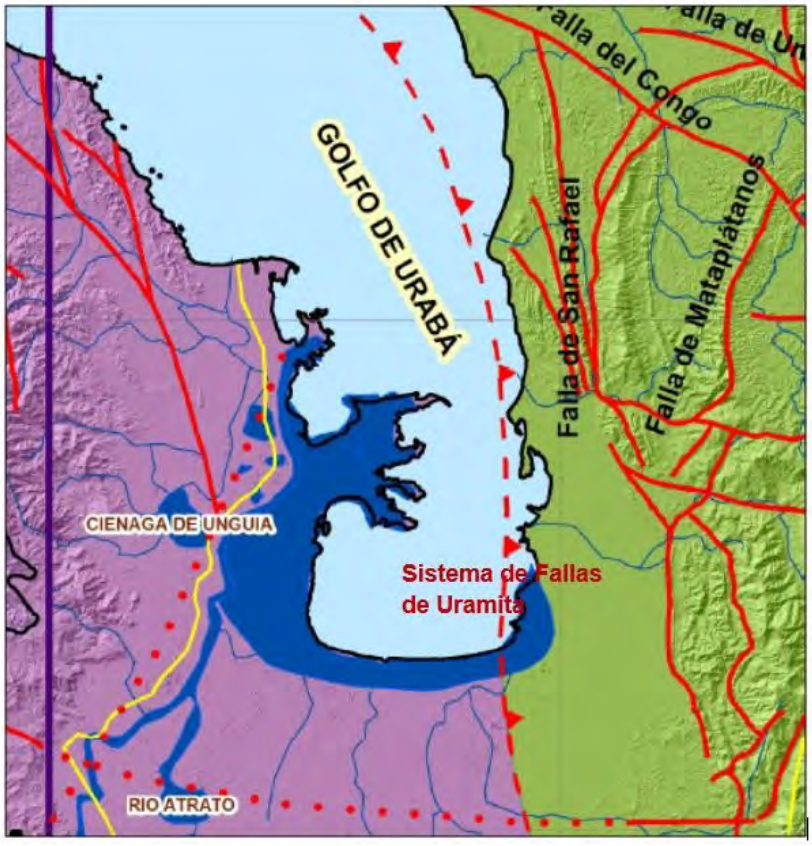


Figure 5.76 Tectonic diagram of the Urabá region, showing the Uramita Fault.
Source: INGEOMINAS 1999 and 2005, in *PIO S.A.S*, 2015[134]

Due to tectonic activity in the Gulf of Urabá and the presence of faults, the rock massif is highly likely to be altered and fractured in its shallowest structure, thus providing a means for underground water to move around.

- *Geophysical prospections applicable to the area of influence*

Geophysical prospection consists of a set of methodologies that employ physics and mathematical techniques applicable to underground exploration for purposes of seeking or studying mineral resources or useful substances, by means of observations made from the air, from water, on the earth's surface and inside wells or perforations.

[134] Ibid.

In this case, the main material available are specific electrical resistivity tests (**ERT**), correlated with observations on installed piezometers, water extraction wells and geological and geotechnical campaigns carried out for the purpose of designing and constructing the port infrastructure.

Table 5.35 and Figure No. 5.77 below provide a summary of the existing tests and records that are applicable to the subsequent hydrogeological interpretation of the area of influence.

Table 5.35 Data and nomenclature from applicable tests and records in the area influence - Magna–Sirgas coordinates, origin Bogotá (Modified)

Location Type Code X Y

Punto	Tipo	Código	Coor_X	Coor_Y
2	Piezómetros, Pozos, SEV	PzC 03	708742,51	1368963
3	Piezómetros, Pozos, SEV	PzC 04 - Banacol Nueva Colonia	708754,32	1368960
4	Piezómetros, Pozos, SEV	PzC 05 - Edgar Silva	707749,06	1368620
169	Piezómetros, Pozos, SEV	CU_SEV_8 - Uniban	708426,29	1368886
179	Piezómetros, Pozos, SEV	GUAD_SEV_4	708858,73	1368314
205	Piezómetros, Pozos, SEV	Finca Iris Recreo	708533,06	1365906
207	Piezómetros, Pozos, SEV	Banacol nueva Colonia 1	708742,51	1368963
208	Piezómetros, Pozos, SEV	Banacol nueva Colonia 2	708754,32	1368960
209	Piezómetros, Pozos, SEV	Edgar Silva	707749,06	1368620

(Piezometers, Wells, ERT)

Source: CORPOURABA, 2011[135]

[135] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). (Evaluation of hydrogeological information derived from the perforation of deep wells and vertical electrical soundings). 2011

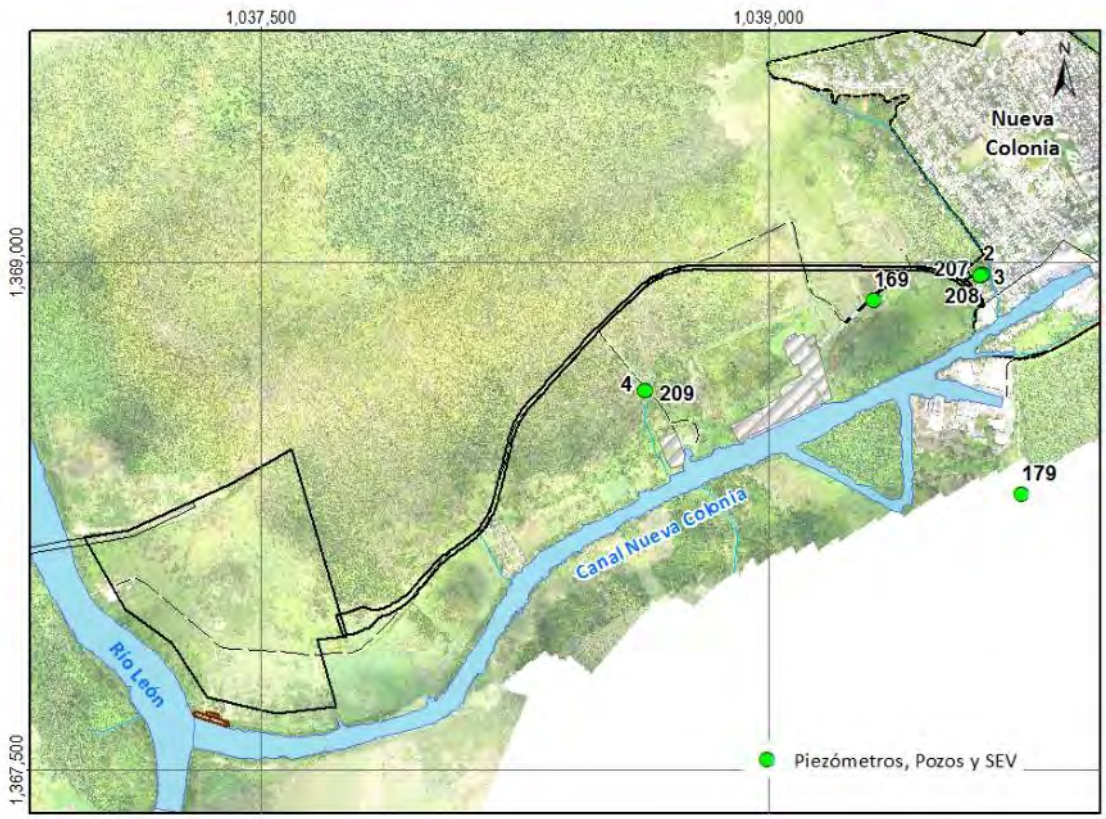


Figure No. 5.77 Location of piezometers, wells and ERT in the area of influence.
Source: *Aqua & Terra Consultores Asociados S.A.S.*, 2015

Electric resistivity is a physical property that varies for each type of medium in which it is measured. It can be used to determine differences in the lithological makeup of a land, rock or fluid mass.

The most commonly used technique on the surface to discover the distribution of electrical resistivities over depth is vertical electric sounding (VES). Its geoelectrical method uses resistivity values and contrasts to determine at which depths the units with different resistivity values can be found, based on the interpretation of an observed curve of apparent resistivities. The interpretation of the sounding curves obtained in the field, with theoretical parameters and known records of stratigraphic columns, allows the sounding to be interpreted.

- Method Basis:

When current by conduction is applied to the ground using electrodes, any variation in conductivity in the subsoil alters the flow of current within it, which in turn affects the distribution of the electric potential.

The extent to which surface potential is affected depends on the size, location, form and conductivity of the material that makes up the section being investigated, by means of the measurements of potential taken on the surface. The usual practice is to use two electrodes to inject a current into the subsoil, and then measure the difference in potential between a second pair of electrodes located in a line between the first. A value entitled “apparent resistivity” can be calculated from the potential difference measurements, the current applied and also the separation of electrodes.

The variation in apparent resistivity, with changes in the position of or spacing between the electrodes, provides information regarding variations in the stratification of subsoil.

The sounding curves are interpreted with the help of mathematical models or pattern curves, which is represented in a bilogarithmic diagram where the resistivity (Ohm-m) and depth (thickness-m) of the various layers that make up the subsoil are worked out.

Typical electrical resistivity values for different material types are shown below in Table 5.36.

Table 5.36 Typical electrical resistivity values

Material Type	Resistivity (Ω-m)
Sound base rock with spaced diaclases	>10000
Fractured base rock	1500-5000
Fractured base rock saturated with running water	100-2000
Fractured base rock saturated with salt water	50-100
Partially saturated gruss	500-1000
Saturated gruss	40-60
Partially saturated saprolite	200-500
Saturated saprolite	40-100
Partially saturated gravel	500-2000
Saturated gravel	300-500
Partially saturated sand	400-700
Saturated sand	100-200
Partially saturated loess	100-200
Saturated loess	20-100
Loess saturated with salt water	5-15
Partially saturated clay	20-40
Saturated clay	5-20
Clay saturated with salt water	1-10
Dry volcanic ash	1000-2000
Moist volcanic ash	300-1000
Saturated volcanic ash	100-300

Source: BIOEXPLORA S.A. 2009[136].

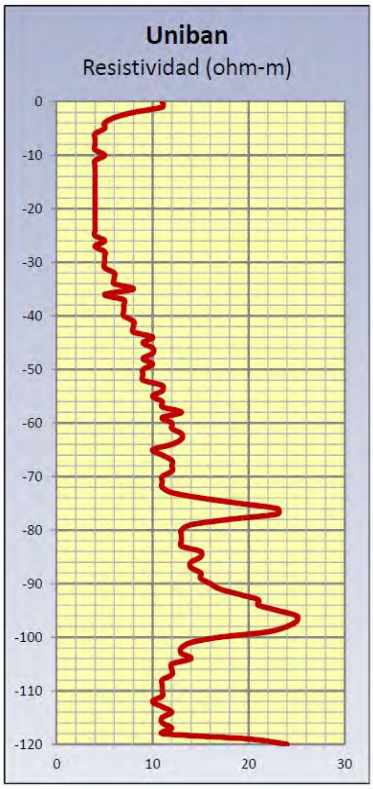
In accordance with the records from wells, piezometers and electrical resistivity tests which are available for the area of influence and correspond to the basis of this evaluation, the field reports for the area of influence and applicable wells are shown below in Table 5.37 and Figure 5.78 to Figure 5.80.

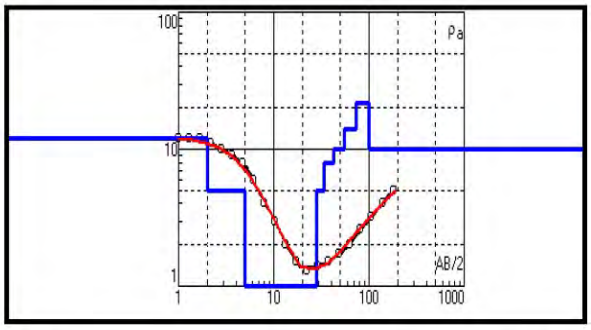
Table 5.37 Record of electrical resistivities from existing tests and explorations in the area of influence

Location	ISORES50	ISORES100	ISORES190	ROOF_T	BASE_Q	Thick-ness Tw	Thick-ness clay-stone
CU_VES_8 Uniban	10	20	10	-	100	-	-
GUAD_VES_4	9	9	9	-	95	-	-
Iris Recreo Farm	-	-	-	-	96	-	-
Banacol Nueva Colonia 1	-	-	-	-	98	-	-
Banacol Nueva Colonia 2	-	-	-	-	-	-	-
Edgar Silva	-	-	-	-	95	-	-

Source: CORPOURABÁ, 2011 [137]

[136] BIOEXPLORA S.A. (Hydrogeological study in the Agriban farm in the banana-growing region of Urabá for hydraulic well design). 2009. 44pp.
[137] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). 2011. Op. Cit.





N	ρ	h	d	Alt
1	12	2	2	-2
2	5	3	5	-5
3	1	23	28	-28
4	5	6	34	-34
5	8	9	43	-43
6	10	12	55	-55
7	14	19	74	-74
8	22	26	100	-100
9	10			

Figure 5.78 Record RegisCU_SEV_8 Uniban
Source: CORPOURABÁ, 2011 [138]

Lithographic Column	
Piezometer no. 5, Edgar Silva Farm	
Interval	Interval Description
0-4	Clay, mid-grey to greenish-grey, mottled with brown, ochre, iron oxides, medium hardness, plastic, low solubility.
4.0-6	Black sand, fine to very fine, abundant loess matrix, angular, good selection. Black chert, abundant vegetable remains (decomposing wood). Presence of clay, as above.
6.0-20	Silty-sandy, mid-grey to black, soluble, remains of decomposing vegetable material. Traces of clay as above, increasing towards the base. Sand to very fine sand. Towards the middle of the sequence there is increased vegetable remains content, at the base the sandy proportion decreases. Some shell fragments.
20-26	Sand, black to mid-grey, loamy, fine to very fine, angular, good selection. Black chert, hyaline quartz. Abundant shell fragments. Clay is maroon to light brown, soluble, somewhat plastic, sticky, vegetable remains.
26-33	Sandy-loamy clay, greenish-grey to olive green, soft, soluble (a lot of the sample is lost en route). Sand is fine to very fine, like the previous interval, presence of shells and vegetable material

[138] Ibid. .

33-38	Sand, black to mid-grey, loamy, fine to very fine, angular, good selection. Black chert, hyaline quartz. Abundant shell fragments.Clay is brown to light brown, soluble, somewhat plastic, sticky, vegetable remains
38-44	Sandy-loamy clay, greenish-grey to olive green, soft, soluble (a lot of the sample is lost en route). Sand is fine to very fine, as above. Presence of shells and vegetable material.
44-60	Sand, brown, light brown, black, high to medium fineness, subangular to subrounded, regular selection. Brown and black chert, hyaline quartz, shells. Little to no decomposing wood. Greenish-grey clay as matrix towards the base, as well as broken and intact shells.
60-64	Clay, light brown, mid-grey to blueish grey towards the base, sticky, rubbery, somewhat soluble, somewhat sandy, traces of silt. Sand is high to medium fineness, shell fragments.
64-95	Sand, black, hyaline, translucent, brown, some red, light green and light brown, fine to fine gravel, subangular to subrounded, poor selection, abundant clayey matrix, light greenish-grey, soluble and sticky. Black and brown chert, hyaline quartz, translucent, fragments of sedimentary and igneous rock. Some shell fragments.
95-130	Interspersed clay, mid-grey to blueish grey mottled with light brown, soft, rubbery, soluble. Presence of sand with 20% fine to medium in 3cm to 6cm layers, with 60% sand, mid-grey, black, very fine to medium, angular to subangular, regular to good selection, little clayey matrix, hyaline quartz and translucent, black chert and 40% clay, mottled, mid-grey to blueish grey and brown, semi-hard, somewhat soluble, breaks up into blocks, traces of shells.
130-153	Sandy clay, 70% clay, mottled, mid-grey to blueish grey, brown, semi-hard, somewhat soluble, towards the base the percentage drops to 60%. Sand, mid-grey, black, light grey, very fine to medium, angular to subangular, regular selection. Hyaline quartz and translucent, black chert. Black chert content increases towards the base, large grain size with some very large.

Figure 5.79 Lithostratigraphic record in piezometer (Edgar Silva Farm)
Source: CORPOURABÁ, 2011 [139]

Lithographic Column – Piezometer no. 04, Banacol Land

Interval	Interval Description
0-3	Clay, dun to light brown, sticky, low solubility, somewhat plastic, towards the base it turns very light brown to greenish-grey, veined and clumpy
3.0-15	Black to dark grey sand, translucent, hyaline, fine to very fine, abundant loamy matrix, subangular to angular, regular to good selection. Black chert, translucent quartz, hyaline. Some shell fragments, clay is blueish-grey and light brown. Abundant decomposing vegetable remains towards the base and blueish to greenish-grey silt.

[139] Ibid.

15-44	Sandy silt, blueish-grey to dark grey, soluble, abundant decomposing vegetable remains. Traces of brown clay like the previous interval. Sand is fine to very fine. Some shells in the section.
44-51	Black sand, translucent, hyaline, fine to very fine to medium, subangular to angular, regular to poor selection, abundant clayey matrix, mid-grey to blueish-grey. Traces of brown clay. Black chert, hyaline quartz, translucent, some broken shells and some intact. Traces of decomposing wood.
51-56	Clay, light brown, soft, sticky, soluble, somewhat sandy, traces of silt. Sand is like the previous interval. Shell fragments. At the base clay is mid-grey to blueish-grey, mottled with light brown.

Figure 5.80 Lithostratigraphic record in piezometer (Banacol land) (Nueva Colonia)
Source: CORPOURABÁ, 2011 [140]

The available data is used to analyze the lithostratigraphic columns, the electrical resistivity information recorded in the ERT and the potential quality of the underground water. The thickness, porosity and transmissivity of the layers that are potentially aquifers are also defined.

In order to calculate the aforementioned properties, the so-called formation factor (F) is taken into account (see Table 5.38). This factor links the grain size of the rock or non-consolidated sediment with the resistivity value, in the following way:

Table 5.38 Formation factor correlations.

Factor	Correlation
1, 2	Clay and loess
3	Fine sand
4	Medium and coarse sand
5, 6	Gravel
7	Not very consolidated to well consolidated rock and sediment

Source: CORPOURABÁ, 2011 [141]

In this way, and based on the lithographic description, each resistivity value in the area of influence was assigned a formation factor value.

[140] Ibid.
[141] Ibid.

For the water quality of the potential aquifer levels, the formation factor is used by correlating the electrical resistivity measured with the ERT (Rf) and the resistivity of underground water (Rw), and by calculating the electrical conductivity of the water (σ) through the following formulas:

$$F = Rf / Rw; \qquad \sigma = 1000 / Rw$$

Table 5.39 Resistivity and electrical conductivity values

VES	Formation Resistivity (Rf)(Ohm-m)	Formation Factor	Water Resistivity (Rw)(Ohm-m)	Electrical conductivity of water (mSiemens/m)
CU-SEV-08	20	4	5	200

Source: CORPOURABÁ, 2013[142]

When the electrical conductivity of the water has been determined, an estimate of the potential amount of Total Dissolved Solids (TDS) can be made using the following formula:

TDS (mg/l) = 7. σ (mS/m)

TDS (mg/l) = 1400; this value corresponds to a classification of **brackish**. As mentioned by Vazquez in his studies, the intrusion of a particular salt wedge could have taken place.

The vertical electrical sounding data and the interpretation of the piezometers and wells in the area were used to ascertain the thickness of the aquifer in the area of influence. In the case of the Quaternary, the thickness values of each aquifer level were added up.

Table 5.40 Thickness of the aquifer in the area of influence

CU-SEV-08	45 (Q)

Source: CORPOURABÁ, 2013[143]

With regards to the porosity of the aquifer, Archie's law can be used to give an estimate of the porosity of the aquifer levels with the following formula:

$F = 1/\varphi^m$

Where F = Formation Factor, and M varies as follows:

Table 5.41 Porosity correlations

[142] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). 2013. Op Cit.
[143] Ibid.

M	Correlation
1.3	Unconsolidated sediment
1.8	Not very compact porous rock
2	Compact rock

Source: ASTIER, 1975[144]

Table 5.42 Porosity and relative porosity of the lithographic unit

VES	POROSITY	EFFECTIVE POROSITY
CU-SEV-08	0.34	0.19

Source: CORPOURABÁ, 2011[145]

A summary of the results obtained is provided below.

Table 5.43 Summary of the aquifer properties in the area of influence, based on VES measurement

Stratigraphy				Water			Texture			
Age	Resistivity	Depth	Lithology	Resistivity (ohm-m)	Conductivity (mS/m)	TDS (ppm)	1/Factor Form	Root	Porosity	Effective porosity
Quaternary	31	1	Fine dry sand							
	9	4	Sand	3	333.33	2333.3	0.33	0.77	0.43	0.28
	3	12	Clay							
	1	25	Sand with salt water	0.25	4000	28000	0.25	0.77	0.34	0.19
	10	55	Loess and clay							
	20	100	Sand saturated with slightly saline water	5	200	1400	0.25	0.77	0.34	0.19
	10		Clay							

[144] ASTIER, J.L. (Geophysics applied to hydrology). *Editorial Paraninfo*. Madrid.343p. 1975.
[145] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). 2011. Op Cit

Source: CORPOURABÁ, 2011[146]

As only indirect measurements of resistivities are available for the area of influence, isoresistivity maps are provided below for the purpose of showing the distribution of resistivities at different depths. A scale larger than that of the project is used and the overall resistivity pattern in the area can be noticed, as well as the probable roof and base of aquifers (see Figure 5.81 and Figure 5.82).

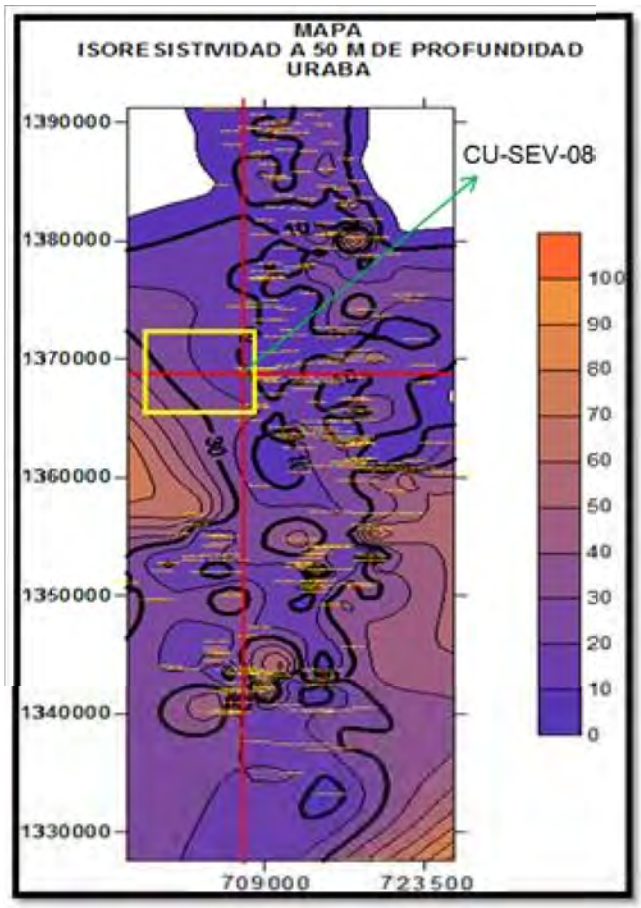


Figure 5.81 Isoresistivity map at a depth of 50m in the Urabá area. (Modified)
Source: CORPOURABÁ, 2011[147]

[146] Ibid.

[147] Ibid.

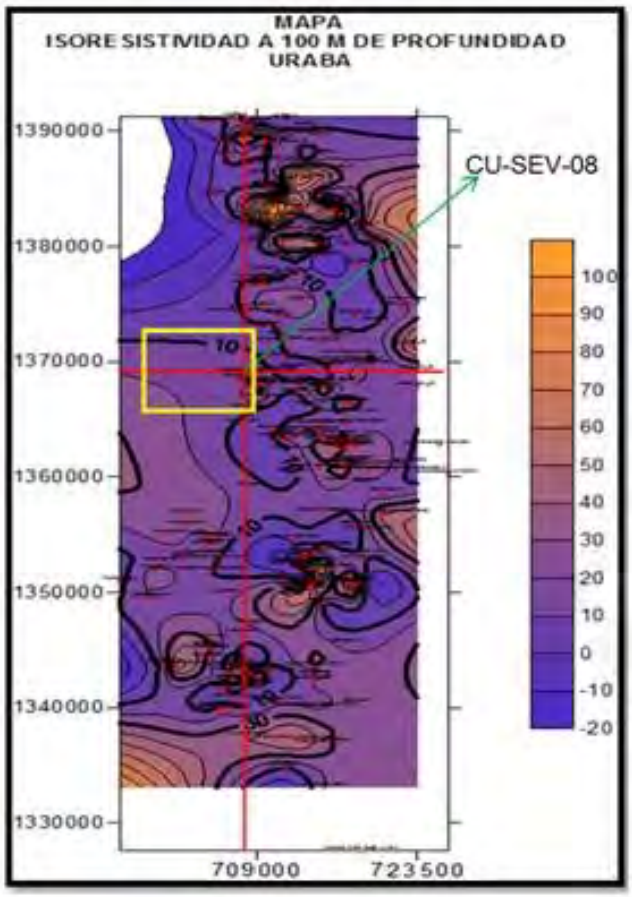


Figure 5.82 Isoresistivity map at a depth of 100m in the Urabá area. (Modified)
Source: CORPOURABÁ, 2011[148]

Due to the non-continuous nature of the aquifers in the Quaternary, it is appropriate to represent the variation in depth of only the last level or the deepest aquifer[149].

[148] Ibid.
[149] Ibid.

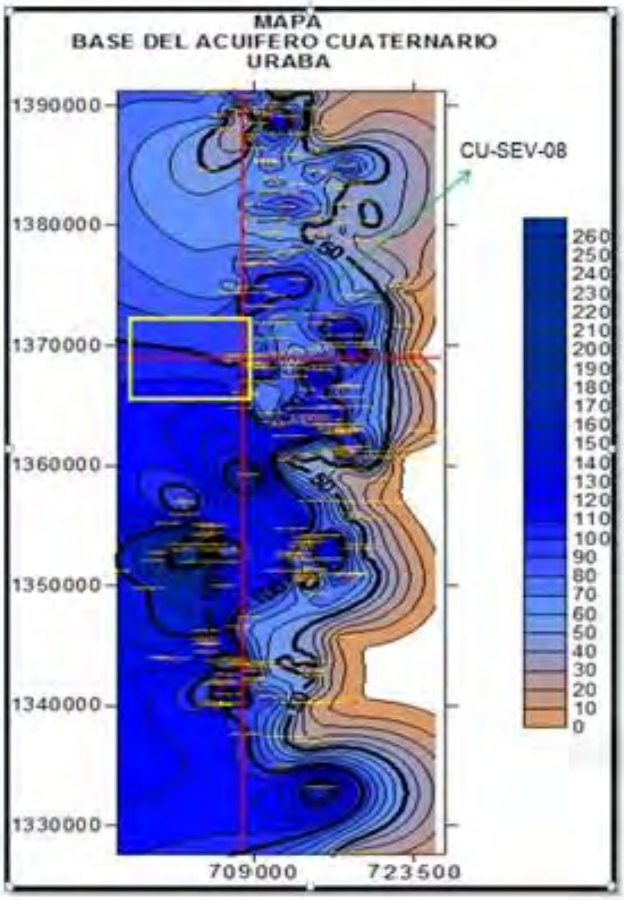


Figure 5.83. Base map of the quaternary aquifer in the Urabá area. (Modified)
Source: CORPOURABÁ, 2011[150]

As can be seen from the isoline records, the depth of the aquifer base in the quaternary lies between 70m and 80m (see Figure 5.83).

[150] Ibid.

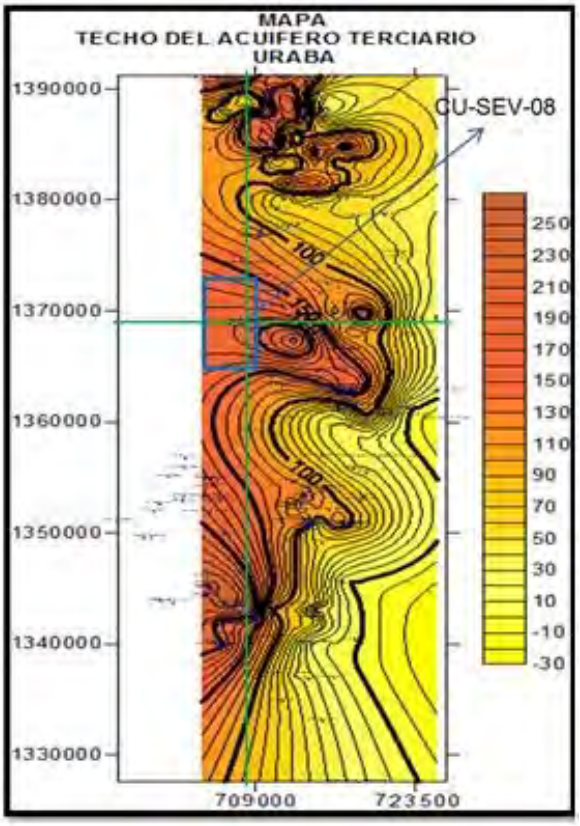


Figure 5.84. Map of the roof of the tertiary aquifer in the Urabá area.
Source: CORPOURABÁ, 2011[151]

It is possible to appreciate that the roof of the aquifer in the area of influence could be located at a depth of around 130m to 150m. In that order of ideas, the thickness of clay between the base of the quaternary aquifer and the roof of the tertiary aquifer varies from approximately 30m to 80m. However, in order to provide a more precise definition of the thickness and extension of the aquifers in the area of influence, more mechanical and geophysical prospecting must be carried out towards the coastline (see Figure 5.84).

- *Stratigraphic cross-sections*

- Description and interpretation of existing stratigraphic cross-sections

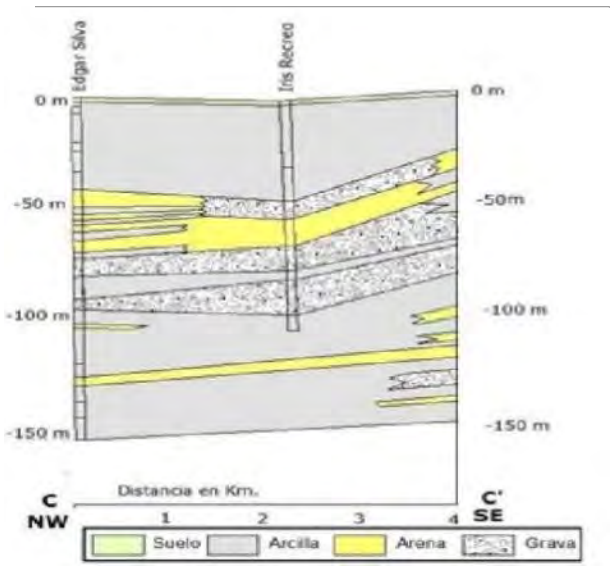
In this section, two (2) lithostratigraphic cross-sections that were obtained for the area of influence are presented. In these cases, only those cross-sections whose

[151] Ibid.

proximity and projection axis make them applicable to the lithostratigraphic characterization of the area are described.

- **Line cross-section 7-8 (Sectorized to the area of influence)**

This cross-section runs in a NW – SE direction (see Figure 5.85) and comprises the *Iris Recreo* and *Edgar Silva* wells. The Edgar Silva well is the closest to the project area, and will be correlated with the mechanical explorations carried out in the area.



Distance in km

Soil Clay Sand Gravel

Figure 5.85. Line 7 – 8 (Modified & Sectorized).

Source: CORPOURABÁ, 2013[152]

At this scale, it can be interpreted that in an east to west direction the roof of the aquifer lies at a depth of 49m in the Iris well, whereas its roof in the Edgar Silva farm can be found at 41m. Likewise, the aquifer base also deepens in an east-west direction, from a depth of 100m in the Iris well to a depth of 95m in the Edgar Silva farm. This aquifer is characterized by displaying repetitive alteration of granular and fine layers with low to medium thicknesses, between 4 m and 6 m[153].

[152] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ).2013. Op. Cit
[153] Ibid.

Separating aquifer levels 1 and 2 is a layer of fine, clayey material that increases in thickness in an east-west direction, from 20m in the Iris well to 30m in the Edgar Silva farm (see Figure 5.86).

After the second aquifer, the layers are made up of fine material and therefore lack hydrogeological importance. The thicknesses of the clay layers increase considerably in depth and direction towards the west[154].

The study carried out for Corpourabá in 2013 determines that in all likelihood there is a change in facies between the first and second levels of the aquifer, which could indicate the boundary between the Quaternary and Tertiary. In this regard, the rhythmic alternation of the fine and granular material in the first level of the aquifer (where fine materials predominate) is characteristic of quaternary fluvial environments; claystones, meanwhile, come from the Tertiary and appear in coarse bundles.

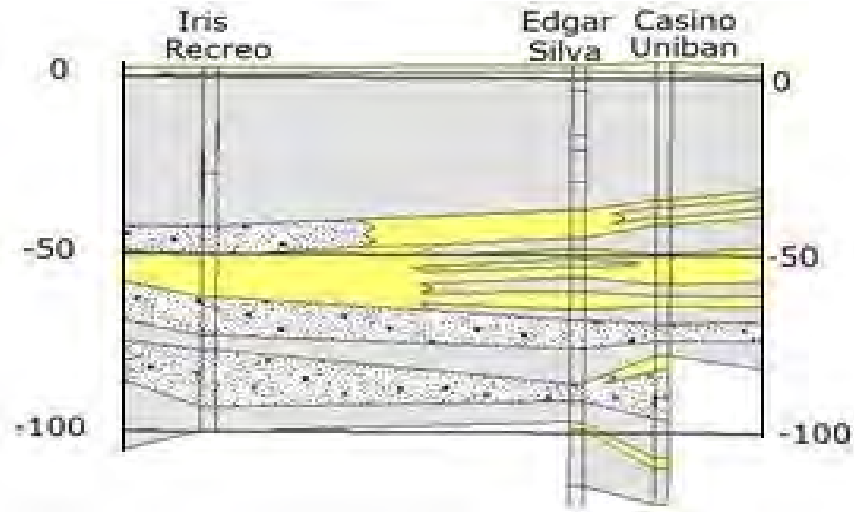


Figure 5.86. Line NS-1 (Modified & Sectorized).
Source: CORPOURABÁ, 2013[155]

It runs from the southwest at the site of the Iris farm in a northwesterly direction towards the Uniban social club, cutting through the Edgar Silva well. The roof of the first aquifer level lies at a depth of 47m in the Iris farm, and decreases gradually to a depth of approximately 55m. The other aquifer level penetrates from a depth of 90m in the Iris farm to 98m in the Uniban social club.

[154] Ibid.
[155] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ (CORPOURABÁ). 2013. Op Cit

The lithostratigraphic inspection of profiles demonstrates a marked tendency to dip in a south-north direction, as well as a marked tendency in an east-west direction towards the discharge area in the Gulf of Urabá and León River. The pronounced south to north dip could be the reason for the deepening that the lithological layers experience in that direction.

All of the layers are supposed to have formed in similar environmental conditions, making it probable that all the layers of the cross-section are from the same geological period (Quaternary).

- ReMI and Reflection Velocity Profiles

The ReMI geophysical profiles are shown below, which use shear wave velocity (Vs) to give an idea of the distribution of materials across depth. It can be correlated with the mechanical exploration measurements taken and also establishes the probable level or depth of the aquifer roof present at the exploration level being studied. These measurements were the result of the geophysical prospecting campaign undertaken by PIO SAS through the *Ulloa y Diez* company (see Figure 5.87 toFigure 5.92).

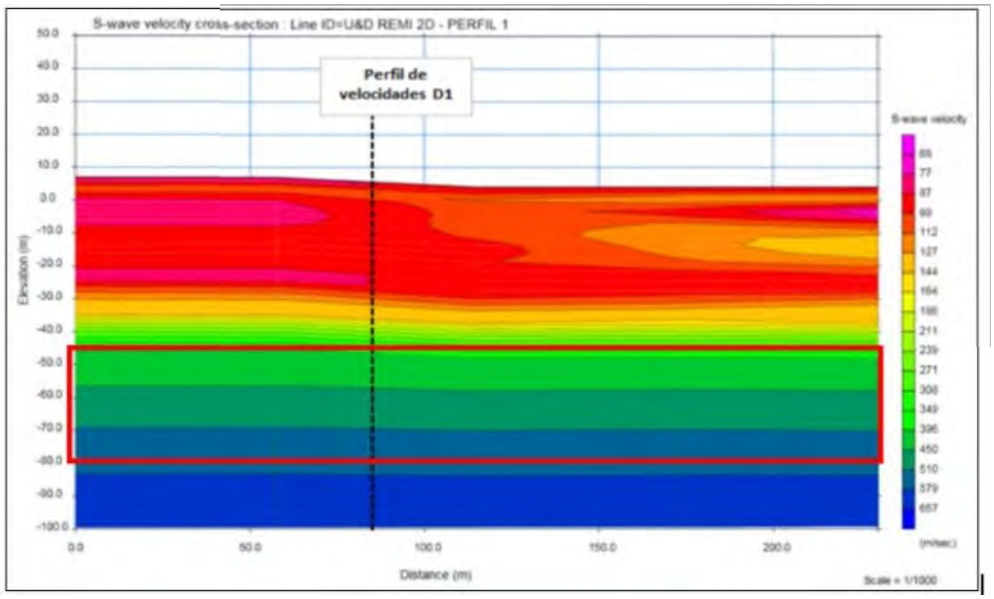


Figure 5.87 ReMI shear wave velocity cross-section (Profile D1)
Source: *ULLOA Y DIEZ LTDA*, in PIO S.A.S, 2015[156]

[156] PIO S.A.S., ULLOA Y DIEZ LTDA (Geophysical exploration with shear wave measurement and sub-bottom profiler for the Puerto Antioquia project), 2014.

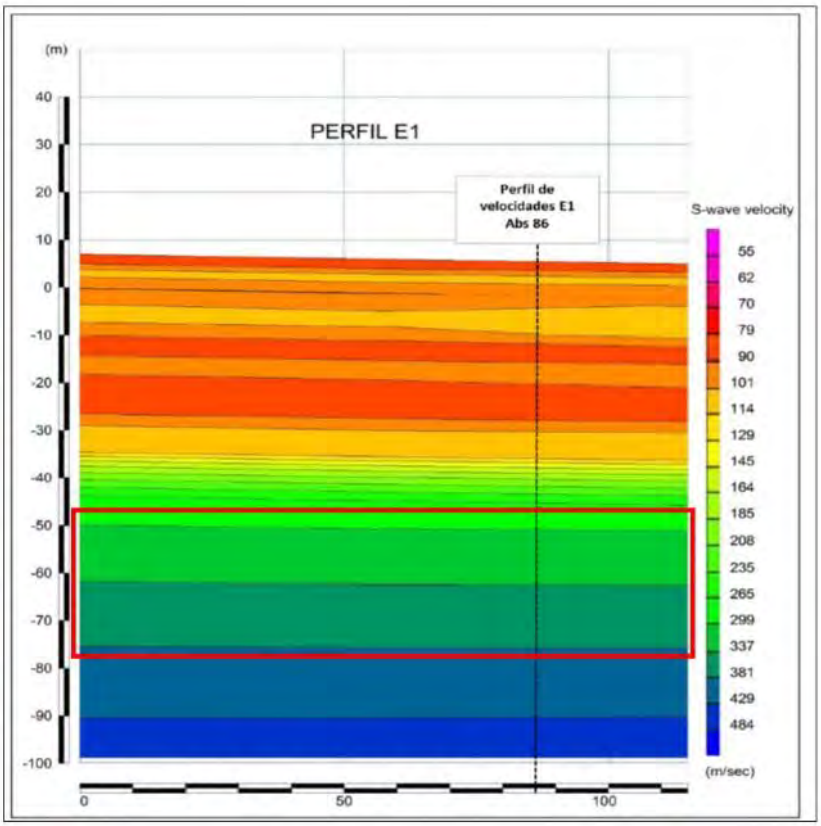


Figure 5.88 ReMI shear wave velocity cross-section (Profile E1)
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[157]

[157] *PIO S.A.S., ULLOA Y DIEZ LTDA*. Op Cit.

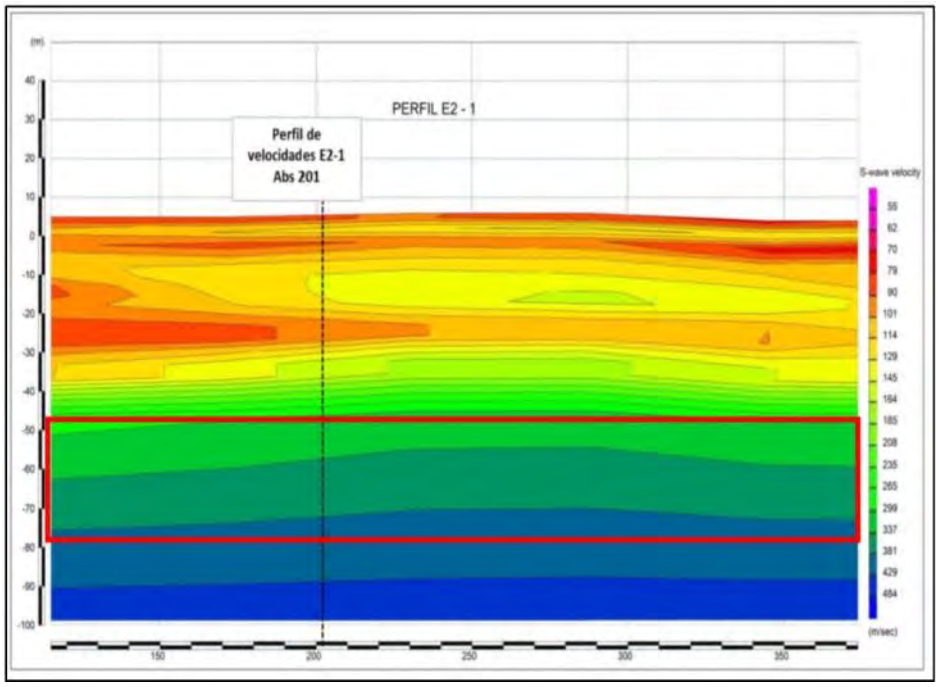


Figure 5.89. ReMI shear wave velocity cross-section (Profile E2-1)
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[158]

[158] Ibid.

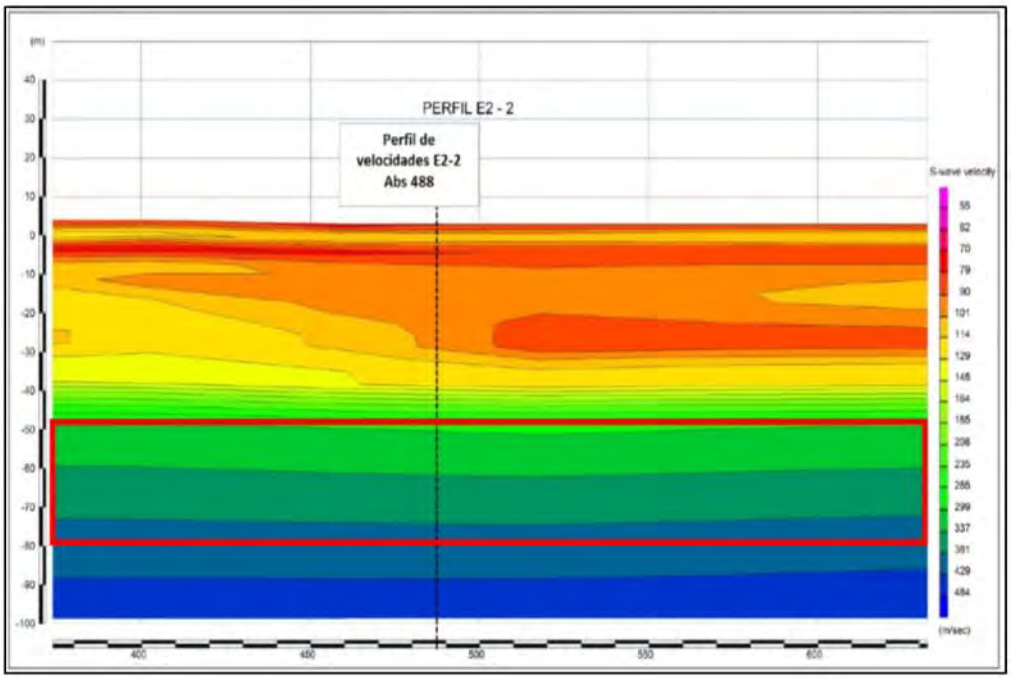


Figure 5.90. ReMI shear wave velocity cross-section (Profile E2-2)
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[159]

[159] Ibid.

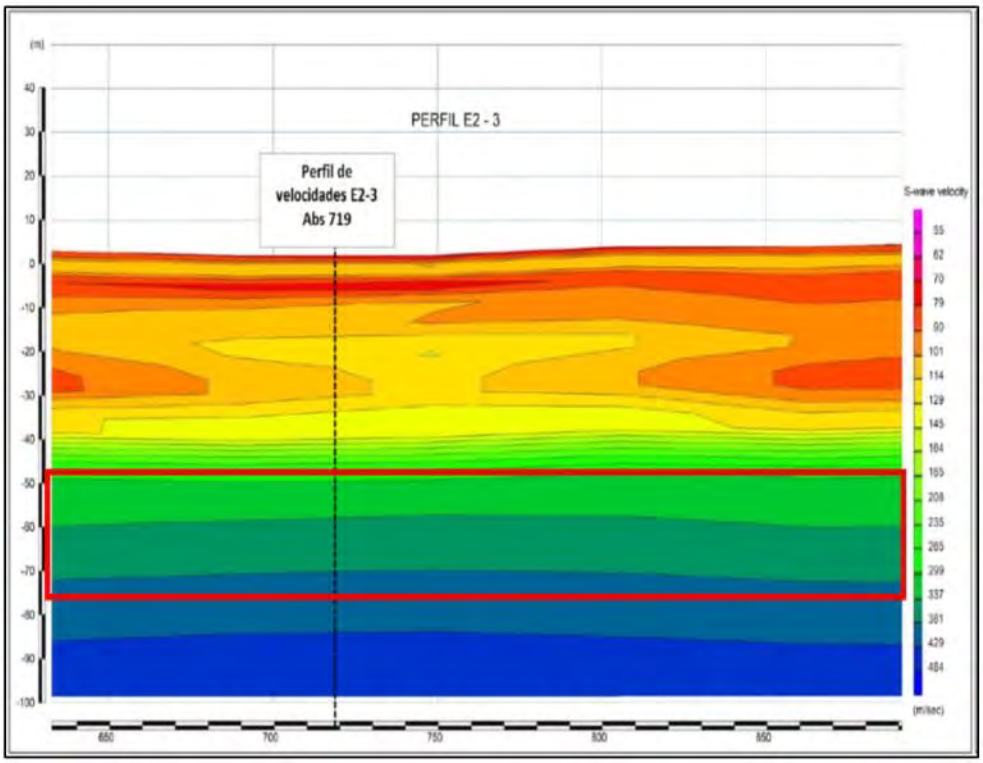


Figure 5.91. ReMI shear wave velocity cross-section (Profile E2-3)
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[160]

[160] Ibid.

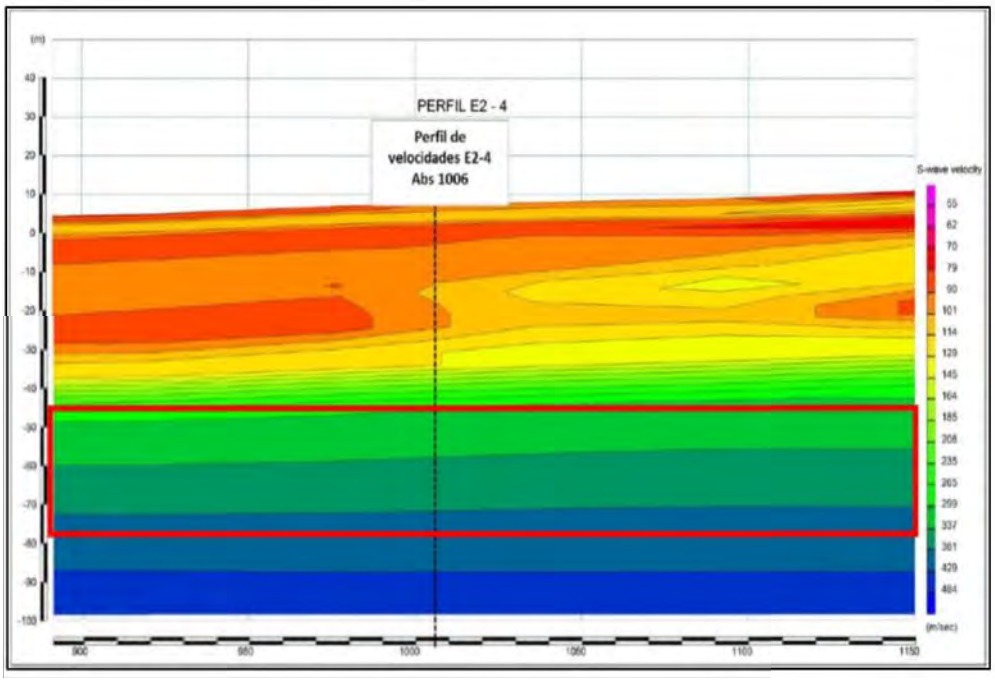


Figure 5.92. ReMI shear wave velocity cross-section (Profile E2-4)
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[161]

In these profiles the presence of materials with shear wave velocities over 180m/s can be observed beyond a depth of 45m. These materials are associated with dense, sandy deposits, interstratified with clays and loess in a lesser proportion. The core of the shallowest aquifer in the area of influence is consolidated at this level and was clear during the mechanical exploration carried out by the Edifica company for PIO S.A.S. (see Figure 5.93). The measurements from the geophysical reflection surveys carried out the Ulloa Diez company in the fluvial and maritime area (see Figure 5.93 toFigure 5.97) are shown overleaf.

[161] Ibid.

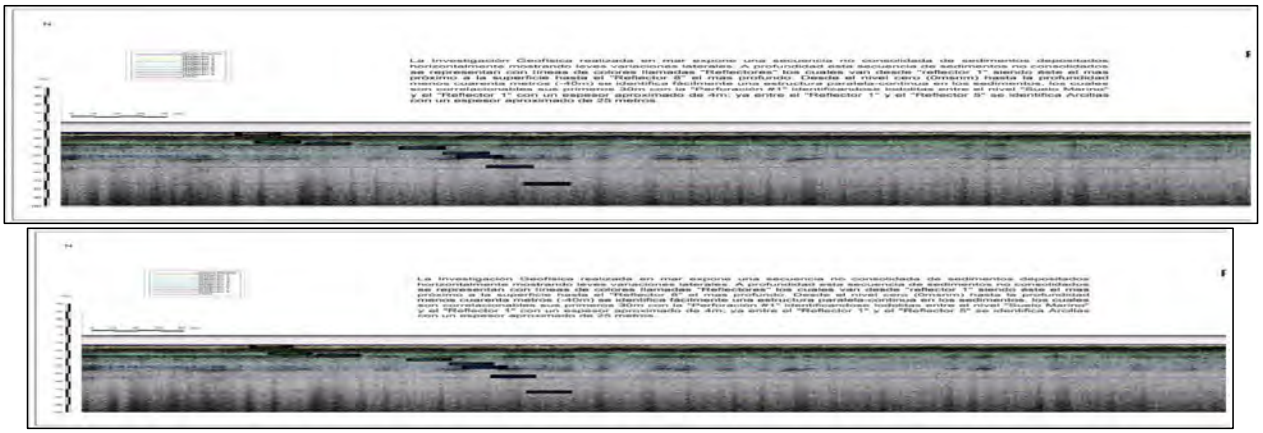


Figure 5.93. Reflection profile A – 1
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[162]

[162] Ibid.

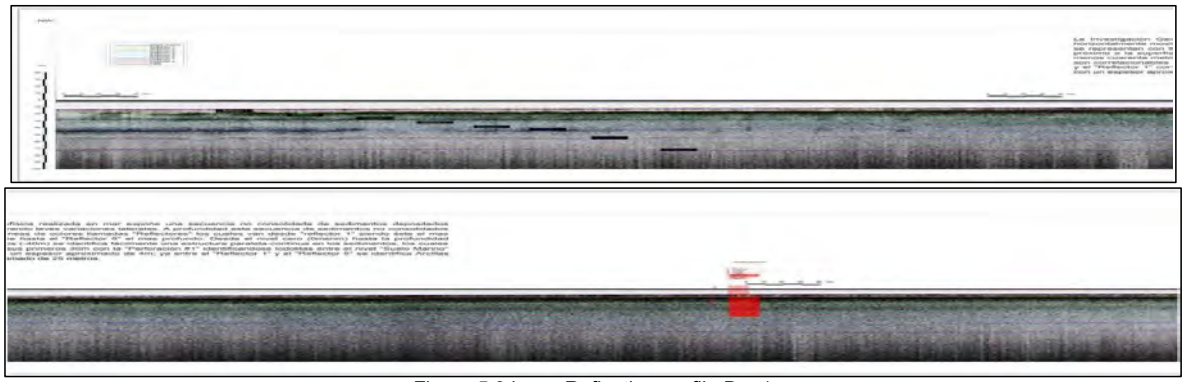
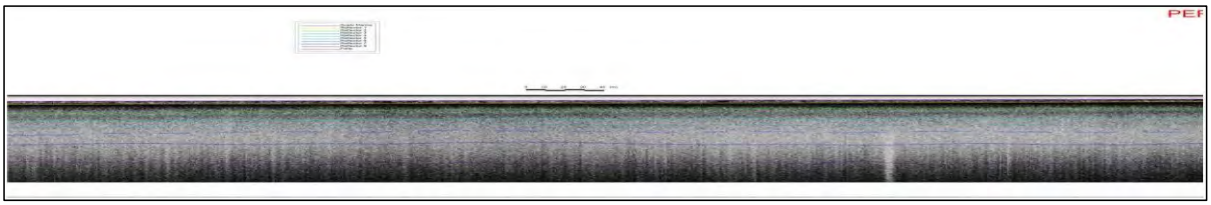


Figure 5.94. Reflection profile B – 1
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[163]



[163] Ibid.

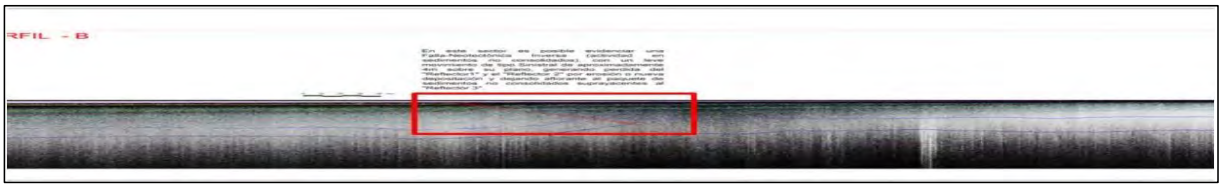


Figure 5.95. Reflection profile B – 2
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[164]

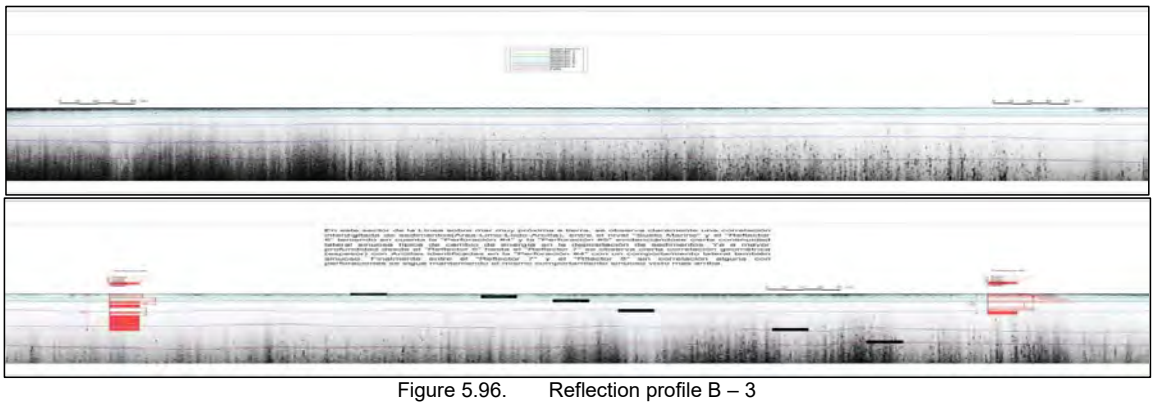


Figure 5.96. Reflection profile B – 3

[164] Ibid.

Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[165]

[165] Ibid.
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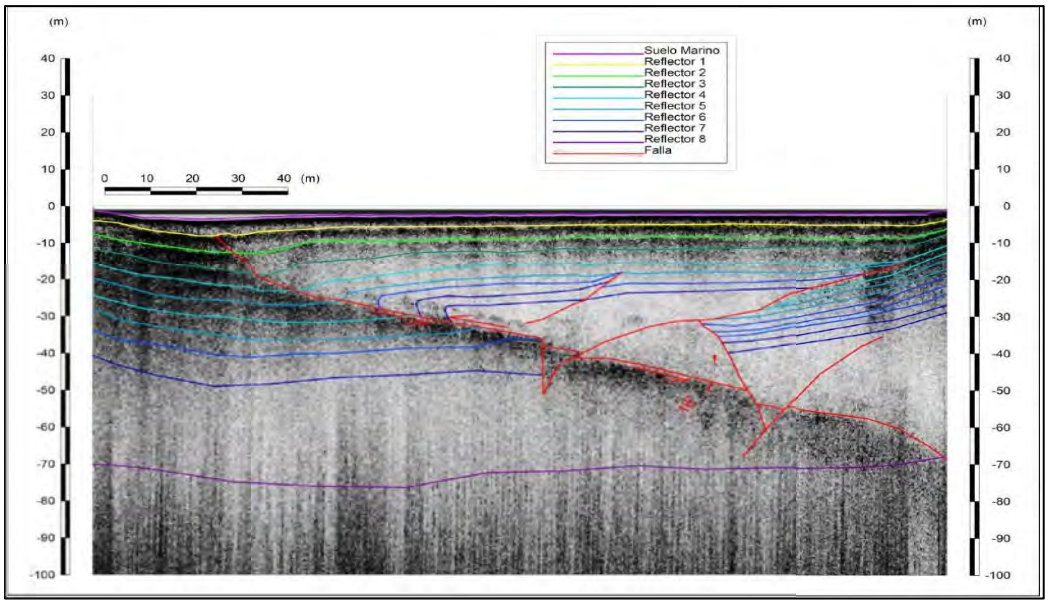

Figure 5.97. Reflection profile C – 3
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[166]

Figure 5.98 and Figure 5.99 show the location of the geophysical ground profiles located in the project's area of influence, in both the marina and inland zones.

[166] Ibid.

Figure 5.98. Location of geophysical ground profiles
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[167]

[167] Ibid.

Figure 5.99. Location of geophysical ground profiles
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[168]

❖ Interpretation of Reflection Profiles

Profile A: The geophysical investigation sets out an unconsolidated sequence of sediments, arranged horizontally with slight lateral variations. Mudstone with an approximate thickness of 4m can be found at the sea floor level, followed by a clay layer of approximately 25m.

Profile B: Aligned in a NW-SE orientation, it shows a sequence similar to that of Profile A, with a mudstone layer roughly 5m thick and clay layers close to 25m, consistent with reflection interpretation. Towards the middle of Profile B (B-2) a type of neo-tectonic inverse fault can be seen, which usually occur in unconsolidated sediment.

Towards the end of Profile B (B3) a correlation of sand, silt, mud and clay sediment can be seen between Reflector 6 and the sea floor level. There is evidence of a certain degree of sinuous lateral continuity, which is characteristic of changes in the energy of sediment settling. The sinuous lateral pattern continues from Reflector 6 downwards.

Profile C: Aligned in a NW-SE orientation, it has an exploration depth of 100m in relation to the river. The graph clearly shows a main neo-tectonic fault type of an inverse nature, resulting from compressional forces and creating other satellite faults on the unconsolidated sediment. This demonstrates the chaotic state of the unconsolidated sediment in the area.

A connection with the mechanical perforations made by PIO SAS can be noticed, agreeing on the existence of a sequence of mudstones on the sea bed, followed by a sequence of loose sand, silt, clay and interleaved sand of high compressibility. These correspond to the alluvial deposits and the flood plain of sedimentary origin.

[168] Ibid.

Piezometric Monitoring

Figure 5.100 below shows the monitoring measurements taken during the geological and geotechnical campaign carried out by the company Edifica Colombia. During the campaign, several piezometers were built and monitored at specific points in the project's area of influence.

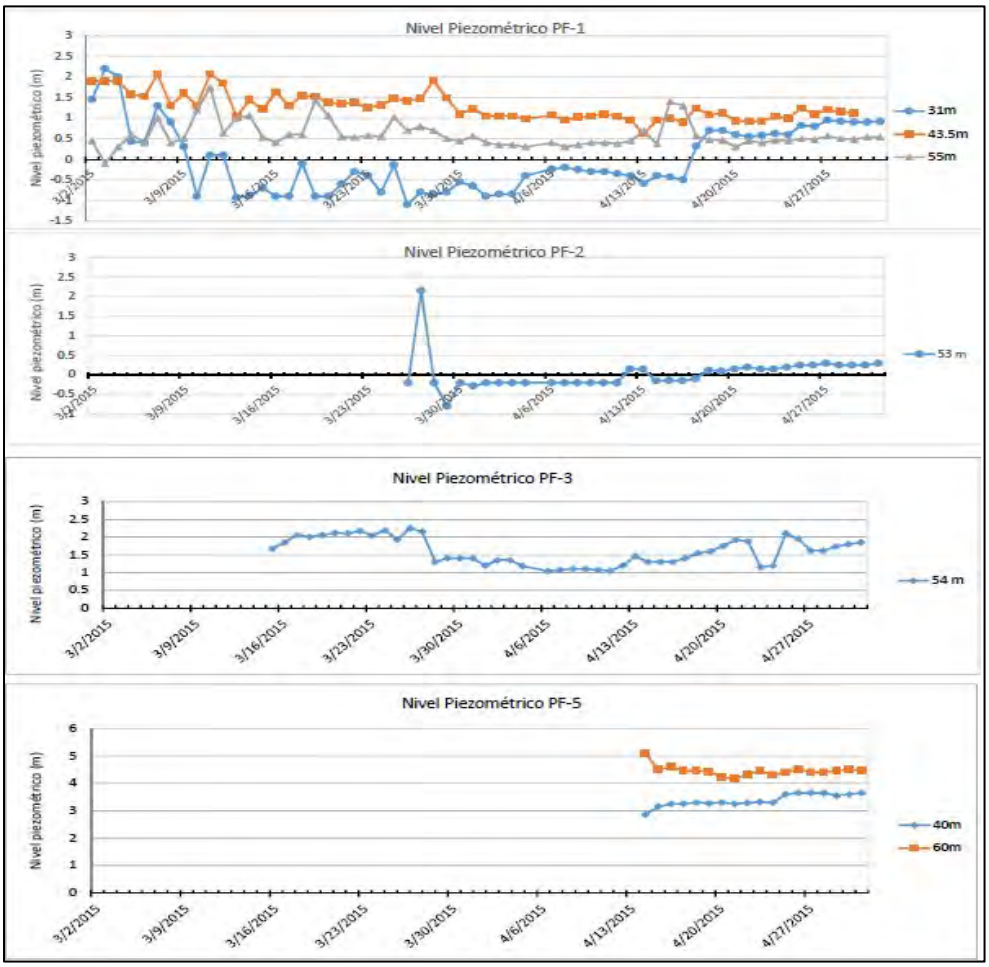

Figure 5.100. Monitoring measurements of piezometric levels taken by Edifica Colombia in the project area.
Source: *ULLOA Y DIEZ LTDA*, in *PIO S.A.S* (2015)[169]

[169] *PIO S.A.S., EDIFICA COLOMBIA LTDA,* 2015. Op cit.

The followings conclusions can be drawn from the measurements taken and monitoring performed during the geological and geotechnical campaign (see Photo 5.27 and Photo 5.28):

The piezometers located in Perforation PF-1, which totaled three (3) at different depths, showed behavior typical of a confined aquifer by maintaining heads of water that reached maximum and minimum levels of 2.10m and 0.25 m respectively above the exploration level, recorded on the deepest piezometers (43.5 and 55m).

With regard to the piezometer located closest to the surface (31m), it shows a variation in the levels of the column of water in the order of 3.35m, from +2.25m to -1.10. This is indicative of water flows inside the aquifer and of interactions between them.

The piezometer located in Perforation PF-2 (53) shows a pronounced spike in the column of water at an approximate height of +2.25m. This point represents a release of pressure at the sampling depth, which subsequently dissipated between -0.80m and +0.25m, according to the water flows at that depth.

The piezometer located in Perforation PF-3 (54m) gives readings that vary little, maintaining a constant high level compared with the depth at which the perforation was made. This is indicative of the presence of a confined aquifer.

The highest water column levels were detected on the two (2) piezometers located in the sea zone PF-5, one at 40m and the other at 60m, with a maximum value of +5.00m and a minimum of +4.10m on the deepest piezometer (60m). Meanwhile, in the piezometer installed at 40m maximum levels of +3.70m and minimum levels of +2.90 were detected. This is indicative of a confined type of aquifer, and of the level of pressure that the aquifer is under despite being in the sea zone.

Photo 5.27 Piezometer installed on land.
Source: *EDIFICA COLOMBIA LTDA*, in *PIO S.A.S* (2015)[170]

Photo 5.28. Piezometer installed in the sea.
Source: *EDIFICA COLOMBIA LTDA*, in *PIO S.A.S* (2015)[171]

[170] Ibid.

[171] Ibid.

- *Hydrogeological profiles*

According to the mechanical exploration work carried out directly in the area of influence, and the geophysical measurements taken by Ulloa Diez, and taking into account the information generated by the Colombian Geological Service (previously INGEOMINAS), Colombia's National University (UNAL), CORPOURABÁ and other governmental and private bodies (see Figure 5.101), the stratigraphic profiles corresponding to the conceptual hydrogeological model of the area of influence (see Figure 5.103 to Figure 5.105) are shown overleaf.

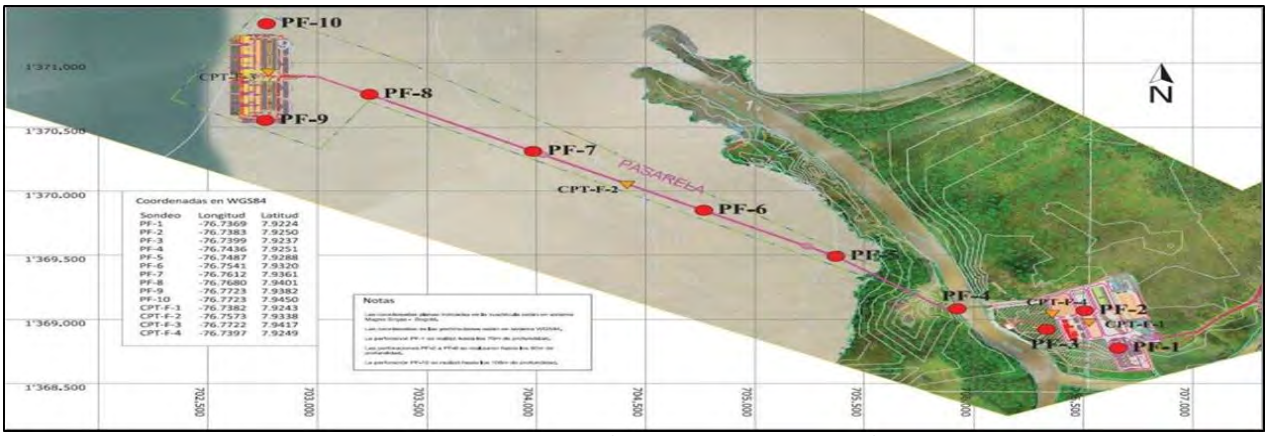

Figure 5.101. Location of ground hydrogeological profiles
Source: *EDIFICA COLOMBIA LTDA*, in *PIO S.A.S* (2015)[172]

[172] Ibid.

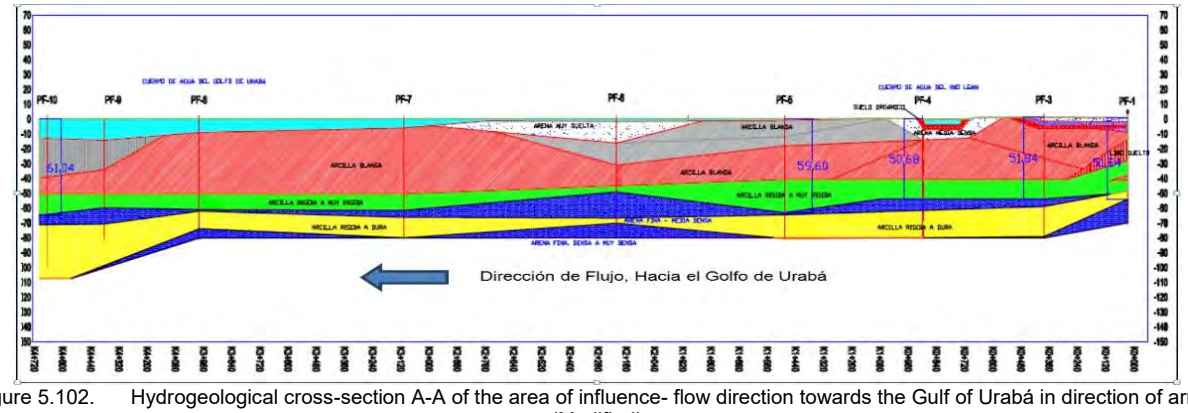

Figure 5.102. Hydrogeological cross-section A-A of the area of influence- flow direction towards the Gulf of Urabá in direction of arrow (Modified)

Source: *EDIFICA COLOMBIA LTDA*, in *PIO S.A.S* (2015)[173]

[173] Ibid.
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[Medellín], 2015

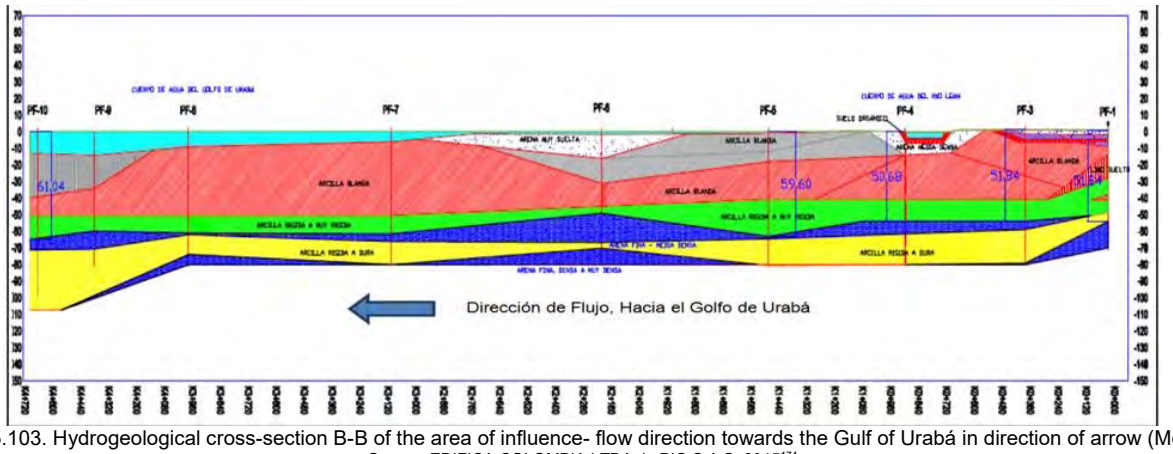

Figure 5.103. Hydrogeological cross-section B-B of the area of influence- flow direction towards the Gulf of Urabá in direction of arrow (Modified)
Source: EDIFICA COLOMBIA LTDA, in PIO S.A.S, 2015[174]

[174] Ibid.
CHARACTERIZATION OF THE AREA OF INFLUENCE
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[Medellín], 2015

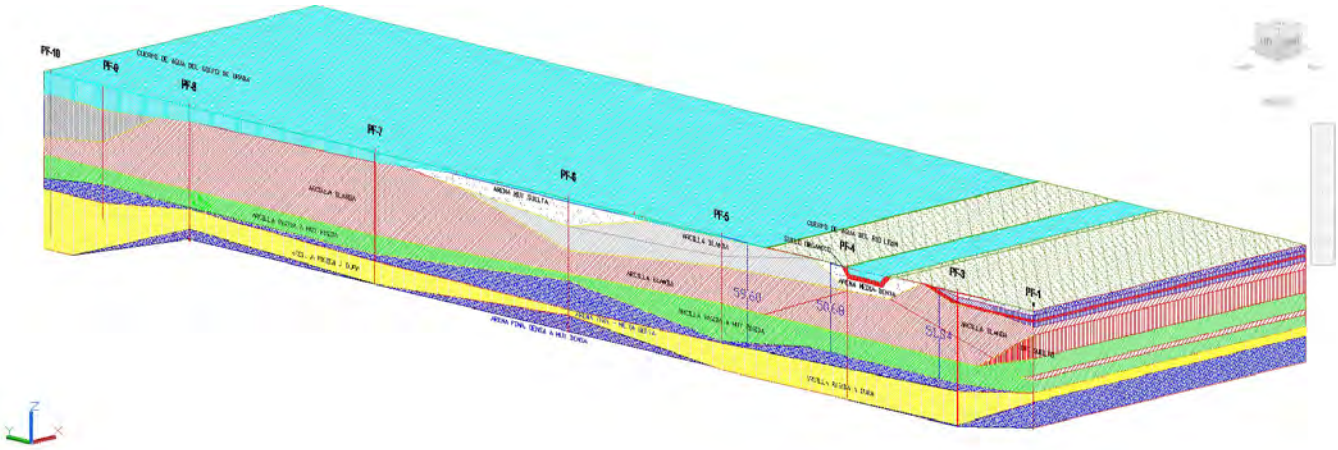


Figure 5.104. Block Diagram in Zone of Influence I
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015)

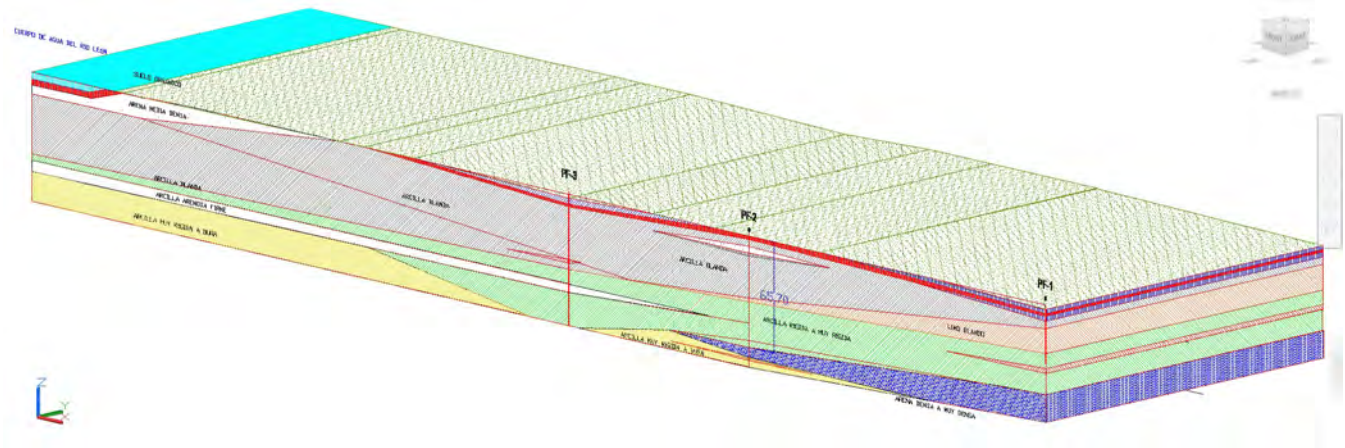


Figure 5.105. Block Diagram in Zone of Influence II
Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015)

- *Evaluation of Aquifer Vulnerability (GOD)*

According to the piezometric measurements, the perforation records in the area and both mechanical and physicochemical laboratory tests, an evaluation of the intrinsic vulnerability of the area of the influence based on the GOD method is provided below. This is the method that best suits the applicable characterization type (see Figure 5.106 and Table 5.44).

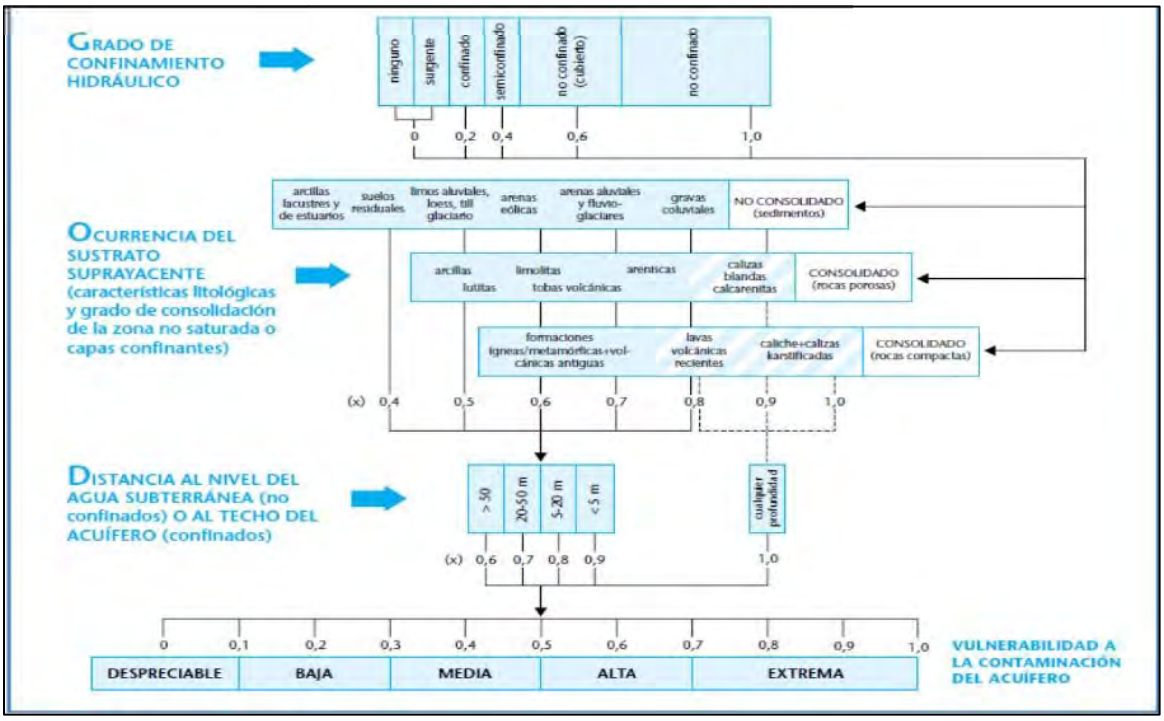


Figure 5.106. Diagram of the GOD method for evaluating intrinsic vulnerability.
Source: Environment, Housing and Territorial Development Ministry (2010)[175]

[175] ENVIRONMENT, HOUSING AND TERRITORIAL DEVELOPMENT MINISTRY. (Methodological proposal for evaluating the intrinsic vulnerability of aquifers to contamination). 2010. 45p.

Table 5.44. Vulnerability classification according to the GOD method

Score	Vulnerability
0.7 – 1.0	Very high
0.5 – 0.7	High
0.3 – 0.5	Moderate
0.1 – 0.3	Low
< 0.1	Very low

Source: Environment, Housing and Territorial Development Ministry (2010)[176]

For our case, there are three (3) levels that contain water in different conditions. The first level has water with some or little flow (0-30m) that is mainly contained within the area's matrix of unconsolidated clayey, loamy and sandy materials. A second level contains the first and shallowest of the confined aquifers (43-70m). The third level corresponds to a confined aquifer, the roof of which can be found from 100m, which is estimated to belong to the tertiary formation that does not reach the surface within the overlying alluvial plain (see Table 5.45).

Table 5.45. Results of the evaluation of the aquifers' intrinsic vulnerability (GOD)

GOD				
		(2-30)m	(43-75)m	(130+)m
G	Groundwater occurrence	0.6	0.2	0.2
O	Overall aquifer class	0.4	0.7	0.7
D	Depth	1	0.7	0.6
Vulnerability Index (VI)		0.24	0.098	0.084

Source: *Aqua & Terra Consultores Asociados S.A.S.* (2015)

As the results show, vulnerability falls into the category of **"Low"**, with the upper layers (0-30m) that are in constant saturation being more susceptible to contamination. However, it is highly possible that the rate of contamination into the soil is substantially lower, due to the slow flow conditions in these layers. This theory could be checked by carrying out more inspections in the area of influence.

The confined aquifer levels, which are situated between 43m and 130m and are the most important, have a vulnerability level of "**very low**". This is primarily due to the

[176] ENVIRONMENT, HOUSING AND TERRITORIAL DEVELOPMENT MINISTRY. 2010. Op cit.

depth at which their roof is located, and the lithostratigraphic makeup of the surrounding soil.

The vulnerability map according to the DRASTIC method is shown below over a more extensive area. Created by CORPOURABÁ in 2002, it shows that the area of influence is classified as of low vulnerability in the coastal zone of the Gulf, becoming of moderate vulnerability as it advances towards the continental shelf, as depicted in Figure 5.107.

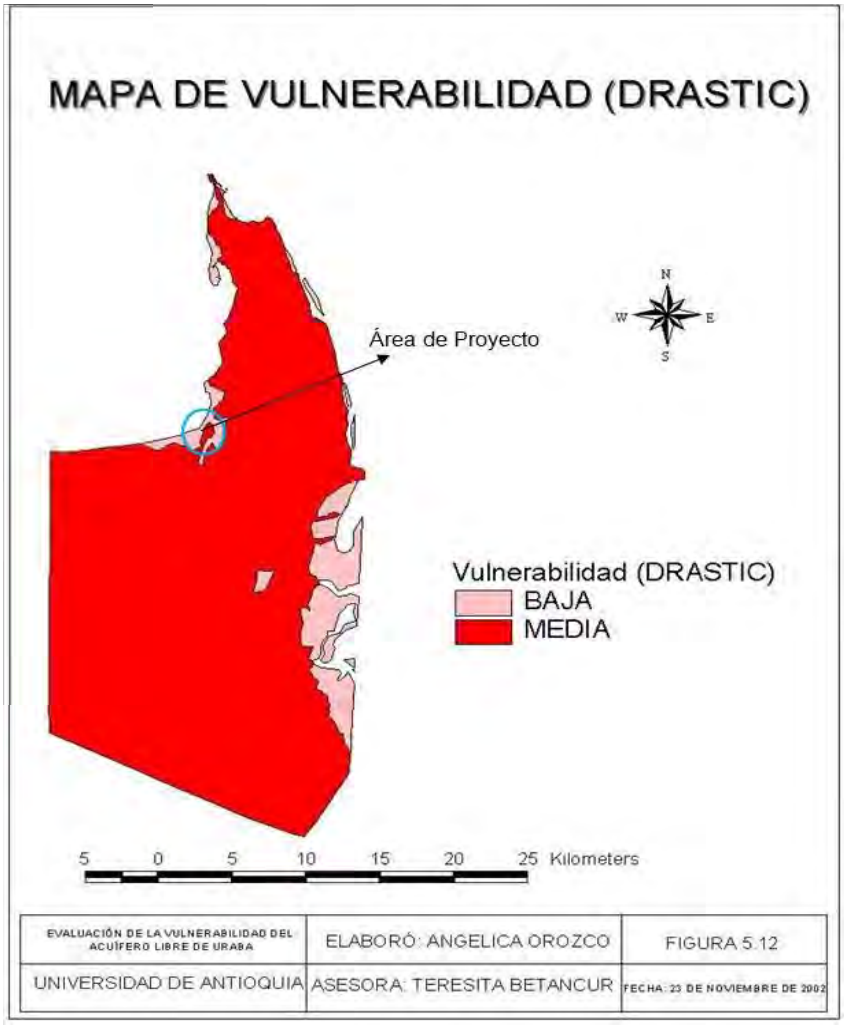


Figure 5.107. Vulnerability map of the Gulf of Urabá. Low vulnerability shown in pink and medium vulnerability shown in red. (Drastic model, 2002).

Source: CORPOURABÁ – University of Antioquia (2002)[177].

- *Conclusions*

- Recharge areas (RA)

These are the points where the water table intersects the ground's surface, giving rise to springs, streams and marshy areas or directly feeding the bodies of water that are established as a base line. In this report, the recharge area has been determined to primarily correspond to wide expanses of lithographic units T2B and T2C under the alluvial mantles, and can be found on the surface from the foothills of the Abibe Mountains. These units are considered to be suitable for the recharging and storage of underground water.

It is also noteworthy that the dips in the catchment area mainly run in an east-west and south-north direction, which would facilitate the recharging of the aquifers.

The areas have been considered based on existing knowledge of the area and previous studies carried out by various organizations, and also due to their flat to undulating topography, present geomorphology and geographical position.

In geomorphological terms, the catchment areas of the León River and River Currulao also represent areas where the appropriate conditions exist to enable water originating from run-off and precipitation to seep into the subsoil. The catchment area has large expanses of alluvial plains connected with the bodies of water, in addition to granulometry and the formation of granular material.

- Infiltration Zones (IZ)

These are areas of high permeability and low gradients, where rainfall infiltrates and creates subsurface flows, or feeds free aquifers that regulate the water cycle. Infiltration zones maintain water supply in the dry season.

[177] CORPOURABA – UNIVERSITY OF ANTIOQUIA. 2002.

Very few zones of this type can be found in the area of influence. This is due to the primary makeup of the clayey layers on the surface of the alluvial plain, which despite being low gradient also has low permeability levels.

- Lithology

Tertiary sedimentary rocks do not surface in the area, and its lithology corresponds to a Quaternary alluvial plain. However, the existence of the two Tertiary units is clear; one from a marine formation environment (Unit T1) without hydrogeological significance, and the other from an inland environment (Unit T2) which is more recent than the first and is of hydrogeological significance.

- Granulometry

Broadly speaking, granulometry decreases gradually from south to north and from east to west, occurring in the mechanical perforations made and giving profiles of alluvial material at great depths, consisting of sand, silt, clay and mud. It should be mentioned that in the studies carried out by Corpourabá for a larger scale, this pattern is associated with an absence of igneous and metamorphic rocks in the area. This is highly consistent with the geological map of the area.

- Dips

The lithographic layers in the area show a pronounced dip in an east to west direction and a gentler one in a south to north direction. In general terms, the east-west dip may indicate that the primary area is located in the east of the catchment area. On the other hand, studies indicate that the south-north dip can be assumed to be associated with the process through which the landmass gains ground on the sea due to the coastal sediment deposition that has taken place in the Gulf of Urabá during the Holocene[178].

Closest to the coast, a marked discontinuity in silt – clay – sand sequences can be appreciated, with no apparent organization.

[178] CORPORATION FOR SUSTAINABLE DEVELOPMENT IN URABÁ –CORPOURABÁ. 2013. Op. Cit.

5.1.9 Oceanography

The Caribbean Sea is one of the two parts of the Intra-Atlantic Sea, which with an approximate surface area of 2,523,106 km2 and approximate volume of 6,483,106 km3 is the largest regional sea of the Atlantic Ocean (see Figure 5.108). It is separated from the main basins of the Atlantic Ocean by a series of small islands[179] and is divided in three principal parts: the Venezuela Basin in the east, the Cayman Sea in the west and the Colombia Basin in the central and south-western region[180].

To the north it extends as far as the Greater Antilles and as far as the coast of Venezuela and Colombia to the south. It is made up of a relatively deep basin, divided into five sub-basins: Granada, Venezuela, Colombia, Cayman and Yucatán (see Figure 5.108). The Caribbean Sea plays an important role in the mass balance of the Atlantic Ocean[181].

In tropical seas, oceanic water tends to display a defined vertical stratification, forming overlaying layers that are primarily differentiated by their density. The vertical structure of the Caribbean Sea shows highly stratified waters in the first 1200m, weakly stratified waters between 1200m and 2000m and very uniform waters below depths of 2000m[182]. The variable seabed topography and extremely irregular coastline may have a significant effect on physical processes in the region[183].

[179] SHENG, J., TANG, L. A Numerical Study of Circulation in the Western Caribbean Sea. In Journal of Physical Oceanography. 33. 2049-2069, 2003.
[180] ANDRADE, C.A. (The surface currents in the Colombia Basin observed with drifting buoys. In Magazine of the Colombian Academy of Exact, Physical and Natural Sciences, 25 (96):321-335. 2001
[181] CARTON , J.A., CHAO, Y. Caribbean Sea eddies inferred from TOPEX/POSEIDON altimetry and a 1/6° Atlantic Ocean model simulation, J. Geophys. Res. 104(C4):7743-7752. 1999
[182] WUST, G. Stratification and Circulation in the Antillean–Caribbean Basins. Part I: Spreading and Mixing of the Water Types with an Oceanographic Atlas. Columbia University Press. 1964. 201 p.
[183] SHENG and TANG, 2003. Op Cit

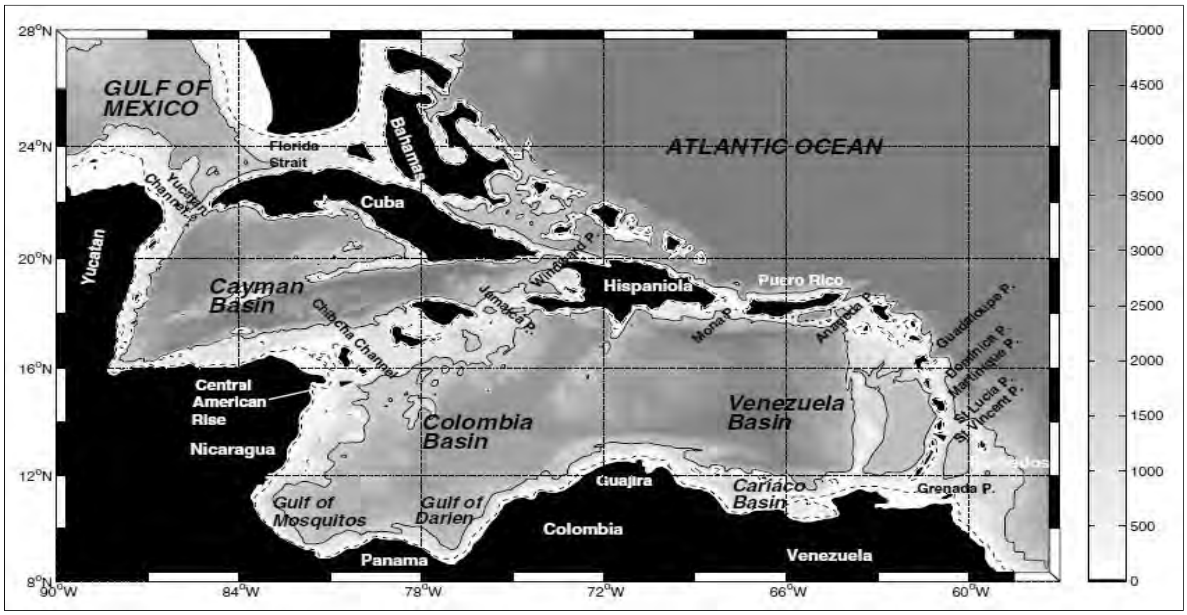


Figure 5.108 Map and bathymetry of the Caribbean Sea
Source: Jouanno et al. (2008)

- Water Masses in the Caribbean

The concept of water masses is used by some oceanographers to define oceanic stratification (vertical structure), while others believe that the masses describe the water's properties. An understanding of properties such as temperature, salinity, dissolved oxygen and nutrients allows the behavior of deep currents to be inferred. Thanks to the conservative properties of temperature and salinity, these parameters have been used to identify and describe water masses by using temperature and salinity graphs with isopycnic lines that links water density to temperature and salinity values[184].

Oceanic water in tropical seas tends to display a defined vertical stratification. The temperature of the Caribbean Sea shows a pronounced gradient, with warm water from the surface to the upper part of the thermocline (a depth of 100m to 200m). The presence of a marked thermocline hinders the vertical mixing of water; the upper layer therefore shows higher temperatures, but from thereon downwards the

[184] LOZANO –DUQUE, Y., MEDELLIN – MORA, J., NAVAS, G.R. (Climatological and oceanographic context of the Colombian Caribbean Sea). In: INVEMAR (Eds.). (Biodiversity of the continental margin of Colombia). Series of special publications, INVEMAR. 2010. 20: 458 p

temperature decreases rapidly. At a depth of 1500m the water temperature is approximately 4ºC, with little variability in the basins of the Caribbean Sea[185].

Salinity shows a variation in the first 1000m of water but stabilizes from this depth onwards, showing higher values than on the surface.

The studies describing the masses of water carried out by CORPES (1992), Urbano (1993), Giraldo (1994) and Andrade (2000) vary in their definition of the number of layers that exist at surface level and their primary characteristics, although their results for the deep layers are matching. This situation demonstrates the variability and instability of the masses of water in the upper layers of the water column, mainly caused by ocean-atmosphere interaction and the contribution of inland waters[186].

According to the work of Giraldo (1994)[187], the Colombian Caribbean shows vertical stratification formed by four masses of water.

1. Tropical Equatorial Surface Layer: located between depths of 0m-50m, with temperature and salinity that vary between 34.5-36ºC and 28 -30 UPS respectively.

2. Subtropical Subsurface Layer: this layer has maximum salinity values between 36.6 and 37 UPS between 0m-200m and an approximate average temperature of 22ºC, and corresponds to the thermal transition zone or thermocline.

3. Sub-Antarctic Intermediate Layer: this corresponds to the layer that extends between 200m and 1000m. The lowest salinity values (34.7-35.15 UPS) are found between 750m and 800m and its average temperature is 6ºC. It enters the Caribbean Sea via the Santa Lucia and San Vicente straits.

4. Deep Caribbean Layer: formed by the deep water of the Atlantic that enters the Caribbean at the threshold level of the Barlovento and Sombrero straits. It is characterized by salinity of 35-35.2 UPS and a temperature of 4ºC, and is located below a depth of 1000m.

[185] WUST, 1964. Op. Cit
[186] Lozano-Duque et al., 2010. Op. Cit.
[187] GIRALDO, L.O. (Analysis of masses of water and quality control of oceanographic information). In: CIOH Scientific Bulletin, 15:17 – 38. 1994.

- Sea Surface Temperature (SST)

The Bernal et al. study (2006) used a series of monthly surface temperature readings from the Comprehensive Ocean-Atmosphere Data Set (COADS) for the 1981-2000 period and determined the variation in temperature for various regions of the Colombian Caribbean. The values for the Gulf of Urabá are as follows: (see Table 5.46).

Table 5.46 Description of SST series

SST	Average	Minimum	Maximum
Urabá	28.16	25.51	29.69

Source: Adapted from Bernal et al. (2006)

The behavior of the SST of the Caribbean Sea at a regional level was obtained from the study carried out by Ruiz et al. (2012)[188]. The authors analyzed the daily surface temperature for the Caribbean between 1985 and 2009 with a resolution of ~4 km using the Advanced Very High Resolution Radiometer (AVHRR) managed by the NOAA.

The Colombian Caribbean shows a southeast to northeast temperature gradient, with temperatures that reach a maximum on the south-eastern Caribbean coast and decrease towards the region of La Guajira. The Gulf of Urabá has the highest average SST in the Colombian Caribbean, with average maximum temperatures of 29.69°C (see Figure 5.109). Bernal et al. (2006)[189] link this temperature pattern to the influence of the Panama-Colombia Gyre (PCG) in the south-eastern region and to the upwelling of La Guajira in the north-east.

[188] RUIZ, M., BEIER, E., BERNAL, G., BARTON, E. Sea surface temperature variability in the Colombian Basin, Caribbean sea. Deep – Sea Research I. 64: 43 – 53. 2012.
[189] BERNAL G., POVEDA, G., ROLDÁN, P., ANDRADE, C.A. (Patterns of variability in the surface temperaturas of the sea on the Colombian Caribbean Coast). In Colombian Academy of Sciences Magazine. 30 (115): 195 - 208. 2006.

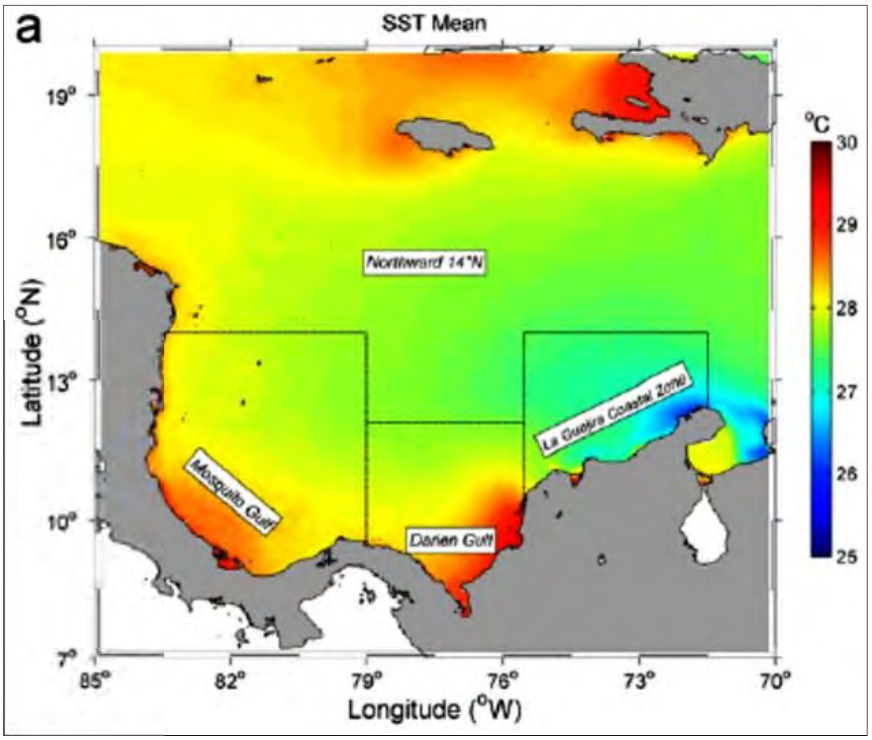


Figure 5.109 Sea surface temperature (SST for the Colombian Basin between 1985 and 2009)
Source: Ruiz et al. (2012)[190].

The seasonal variations in the temperature of the Caribbean Sea are shown in Figure 5.110. In this figure, the greatest variability can be seen to occur on the coast of La Guajira, reaching minimum levels between the months of December and February. This situation could be associated with more intense trade winds and an increase in upwellings in the region[191]. The Gulf of Urabá, meanwhile, shows smaller variations in temperature and reaches maximum levels during the second half of the year (June-November), possibly linked to a decrease in the intensity of trade winds.

[190] RUIZ et al., 2012. Op. cit
[191] BERNAL et al, 2006. Op. Cit.

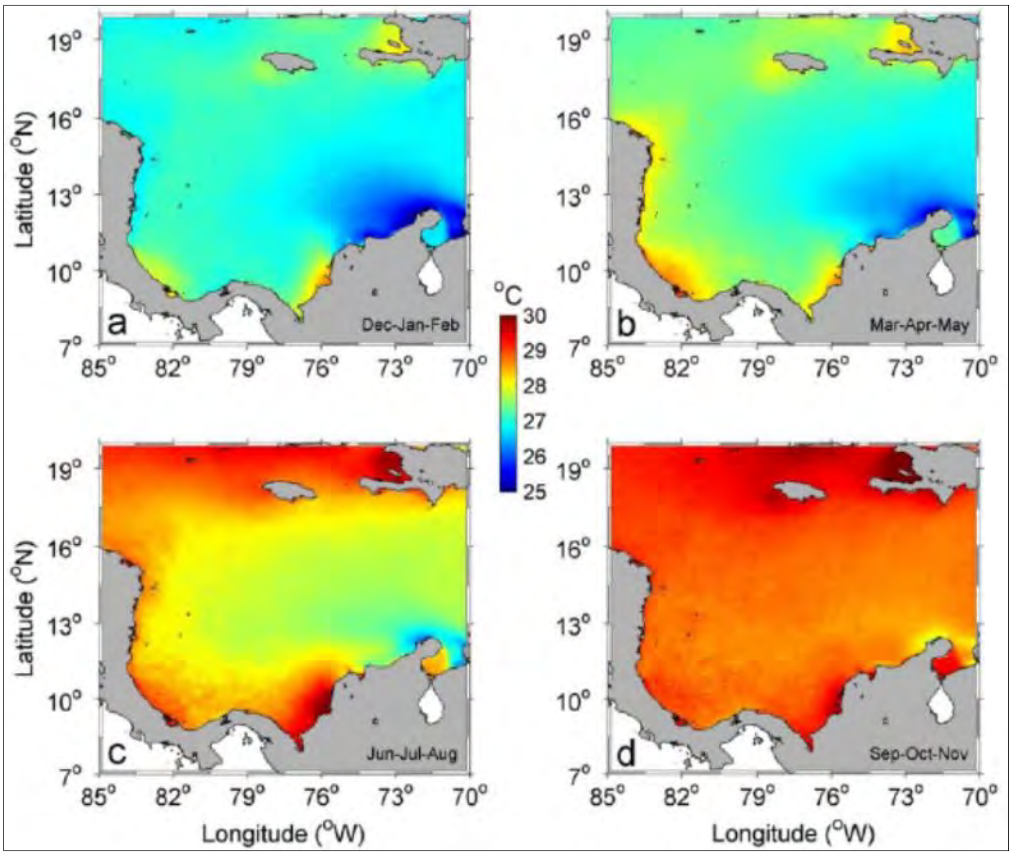


Figure 5.110 Geographical distribution of sea surface temperatures for four climatic seasons a) Dec-Feb b) Mar-May, C) Jun-Aug d) Sep-Nov

Source: Ruiz et al. (2012)[192].

- *Currents*
  - Currents in the Caribbean Sea

The marine currents of the Caribbean Sea form part of the North Atlantic current or gyre system, which itself is primarily made up of the North Equatorial Current (NEC) and the Gulf Stream. The NEC flows from the coast of Africa towards the coast of South America, where it joins the Guiana Current and travels towards the Caribbean Sea. When the current reaches the edge of the Caribbean Sea, it divides into the

[192] RUIZ et al., 2012. Op cit

Antilles Current and the Caribbean Current (CC). The CC transports large amounts of water towards the Caribbean Sea, entering through the arc of the Antilles towards the north-west until it crosses the Yucatán Channel towards the Gulf of Mexico. Upon leaving said Gulf, the CC joins the Antilles Current and together they form the Gulf Stream, which carries warmer water towards the North Atlantic Ocean[193] [194] [195] [196] [197].

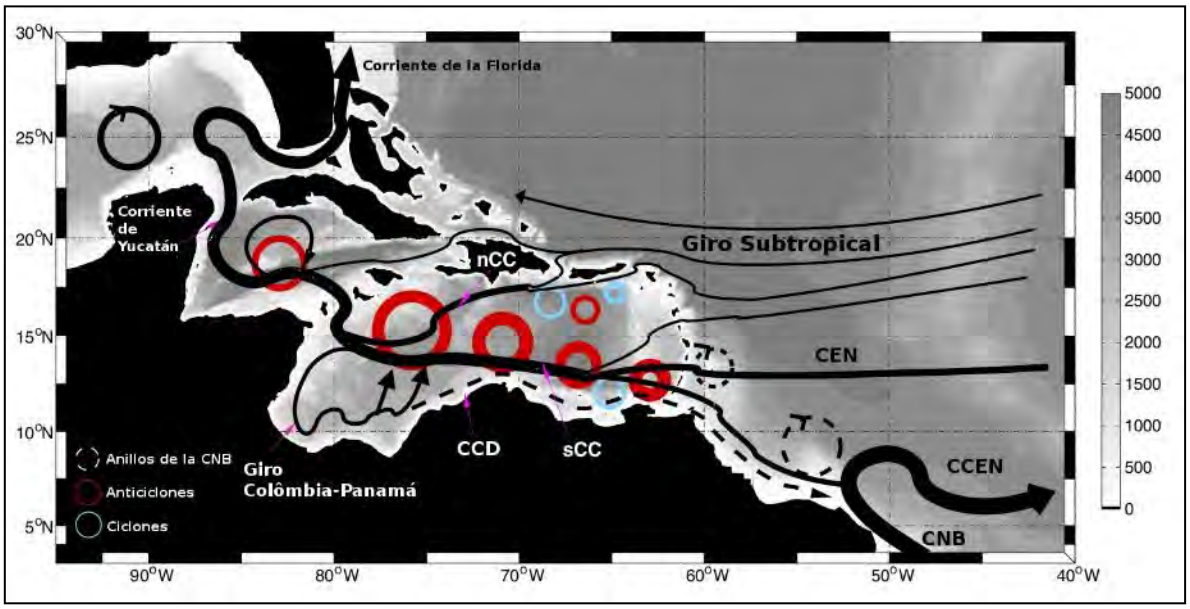


Figure 5.111 Main surface currents in and beyond the Caribbean Sea: the North Brazil Current (CNB), North Equatorial Current (CEN), South Caribbean Current (sCC), North Caribbean Current (nCC) and the Darien Counter Current (CCD). The circles represent anti-cyclonic (red) and cyclonic (blue) currents. The greyscale is bathymetry (m).
Source: Jouanno et al. (2008)[198].

Work carried out regarding the circulation systems between the Atlantic Ocean and Caribbean Sea have demonstrated that water enters in the direction of the

[193] GORDON, A.L. Circulation of the Caribbean Sea. In Journal of Geophysical Research, 72:6207-6223. 1967.
[194] MOLINARI R., SPILLANE, M., BROOKS, I., ATWOOD, D., DUCKETT, C. Surface currents in the Caribbean Sea as deduced from Lagrangian observations. In Journal of Geophysical Research, 86(C7):6537-6542. 1981.
[195] ROEMMICH D. Circulation of the Caribbean Sea: A well resolved inverse problem. In Journal of Geophysical Research, 86(C9):7993-8005. 1981.
[196] HERNANDEZ-GUERRA, A., JOYCE, T.M. Water masses and Circulation in the surface layers of the Caribbean at 66˚W. Geophysical research letters, 27(21):3497-3500. 2000
[197] JOHNS, W.E., TOWNSEND, T.L, FRATANTONI, D.M., WILSON, W.D. On the Atlantic inflow to the Caribbean Sea. Deep-Sea Research Part I, 49:211–243. . 2002
[198] JOUANNO, J., SHEINBAUM, J., BARNIER, B., MOLINES J.M., DEBREU, L., LEMARIÉ, F. The mesoscale variability in the Caribbean Sea. Part I: Simulations and characteristics with an embedded model. Ocean Modelling. 23: 82 – 101. 2008

Caribbean Sea through several passages located between the islands of the arc of the Antilles, between Cuba and South America. The Lesser Antilles form a barrier which prevents the free exchange of water between the Atlantic Ocean and the Caribbean Sea. The masses of water transported by the Guiana Current and the North Equatorial Current run up against this barrier, allowing only surface and intermediate waters to enter from the Atlantic Ocean at high velocities through the island passages[199 200 201 202 203 204].

The water flow that enters the Caribbean Sea is estimated to be within an approximate range of 28 and 30 Sv (Sv = Sverdrup = 106 m3/s). This value has been calculated to be divided up between the passages of the Windward Islands (Grenada, St. Vincent, St. Lucia, Trinidad and Tobago and Martinique) with roughly 10 Sv, the Leeward Islands (Guadeloupe, Dominica, Antigua and Anegada) with approximately 8 Sv and the passages of the Greater Antilles (Mona and Windward) with close to 10 Sv[205 206 207].

Following the effect of the North Equatorial and Guiana currents, the main source of energy for movement in the Caribbean Sea comes from the force of the wind. The trade winds that enter the Caribbean Sea from the east and east-northeast are the driving force behind surface currents. The action of the wind has a direct influence on the surface of the sea, generating movement in the surface layer to an approximate depth of between 100m and 300m (Gordon 1967, Herrera et al. 1980).

[199] HERRERA, L.E., FEBRES-ORTEGA, G. (Thermohaline characteristics of the upper waters of the southeast Caribbean Sea during the rainy season). In Oceanographic Institute Bulletin, University of the East. 15(1):97-114. 1976.
[200] HERRERA, L.E., FEBRES, G.A., ANDRES, J.M. (Distribution of masses of water and their dynamic connections in the central-western Venezuelan region, Caribbean Sea). In Oceanographic Institute Bulletin, University of the East. 19(1 y 2):93-118. 1980.
[201] ROEMMICH D. Circulation of the Caribbean Sea: A well resolved inverse problem. Journal of Geophysical Research, 86(C9):7993-8005. 1981
[202] MORRISON, J.M., NOWLIN, W.D. General distributions of water masses within the Eastern Caribbean Sea during the winter of 1972 and fall of 1973. En Journal of Geophysical Research, 87:4207-4229. 1982
[203] WILSON, W.D., JOHNS, W.E. Velocity structure and transport in the Windward Island passages. Deep Sea Research Part I, 44:487-520. 1997.
[204] JOHNS, W.E., TOWNSEND, T.L, FRATANTONI, D.M., WILSON, W.D. On the Atlantic inflow to the Caribbean Sea. Deep-Sea Research Part I, 49:211–243. 2002.
[205] ROEMMICH, 1981. Op Cit.
[206] WILSON et al., 1997. Op Cit.
[207] JOHNS et al. 2002. Op Cit.

- Currents in the Colombian Caribbean Sea

In addition to being affected by trade winds, the currents in the Colombian Caribbean Sea are influenced by three general conditions:

1. The presence of the Caribbean Current on the surface to a depth of approximately 160m.

2. The Darien Counter Current to the east, whose intensity varies over depth but reaches a maximum velocity (0.1 m/s) focused towards 180 m above the edge of the continental shelf.

3. The deep Caribbean current, which moves slowly towards the east above the slope and deep sea bed (Andrade et al., 2003). The surface current is unstable and transports whirlpools that spin cyclonically and anti-cyclonically and range in size from several dozen kilometers to around 300km in diameter (Andrade and Barton, 2000).

The presence of trade winds generates seasonal patterns in currents, and determines the emergence of areas where sub-surface water upwells off the coast of La Guajira and the Sierra Nevada of Santa Marta, which benefit from the northeast-southwest direction of the coastline (Corredor 1979, Pujos et al. 1986, Blanco 1988, Corpes 1992, Álvarez - León et al. 1995, Andrade et al. 2003). The surface current is unstable and transports whirlpools that spin cyclonically and anti-cyclonically and range in size from several dozen kilometers to around 300km in diameter (Andrade and Barton 2000).

The southern region of the Colombian Caribbean Sea is dominated by the Panamá – Colombia Counter Current and the Panamá – Colombia Gyre. In this region, a flow exists that travels towards the east between the Caribbean Current and the Colombian Coast, and that could be related to the cyclonic spin that dominates the Colombia Basin. Andrade (2001) suggests that this basin is dominated by the cyclonic system known as the Panamá – Colombia Gyre, from which a branch splits off to form the Panamá – Colombia Counter Current. The latter originates in Panama and spins cyclonically within the Gulf of Darién, heading in an eastbound direction along the Colombian coast.

The extension of the Panamá – Colombia Counter Current varies according to the time of year. In the dry season it extends from the Gulf of Darién to the vicinity of the

estuary of the River Magdalena. During the wet season the current reaches as far as the La Guajira peninsula, associated with a reduction in the intensity of trade winds[208 209 210 211 212].

- *Swell*
  - Bathymetry

Two digital terrain models were produced for this study: one pre-construction model to represent the current situation, and another following the projected works to represent the future situation. The model of the current situation takes into account the initial conditions in the area of study, using the Cartographic Atlas of Oceans and Coasts provided by the General Maritime Directorate and produced by the Centre for Oceanographic and Hydrographic Research (CIOH)[213], as well as detailed bathymetry of the area proposed for landfill (carried out by *Batiestudios S.A.S* in July 2015- see Figure 5.112 and Figure 5.113). The nautical charts that contain the area of study are numbers 412 and 625, shown in Figure 5.112.

The second model, representing the final situation, takes into account the dredging of the maneuvering dock, the access channel and the final height of the landfill after the material has been dumped. To that end, inputs of general bathymetry and initial detail were used, and the designs of the final dredging and the dumping that is intended to occur in the area of study were superimposed (see Figure 5.115).

[208] PUJOS, M., PAGLIARDINI, J., STEER, R., VERNETTE, G., WEBER, O. 1986. (The influence of the North Colombian counter-current for the circulation of water on the continental shelf: its action on the dispersion of effluents in suspension in the River Magdalena). CIOH Scientific Bulletin. 6:3-15.

[209] CORPES. 1992. *El Caribe colombiano:* (The Colombian Caribbean- Environmental Reality and Development). Regional Planning Council of the Atlantic Coast, 275 p.

[210] ANDRADE, C.A., BARTON, ED. 2000: Eddy development and motion in the Caribbean Sea. J. Geophys. Res., 105(26):191–201

[211] ANDRADE, C.A., BARTON E.D. 2005. The Guajira upwelling system Continental Shelf Research. 25:1003–1022.

[212] BERNAL G., POVEDA, G., ROLDÁN, P., ANDRADE, C.A. (Variability patterns of the sea surface temperaturas on the Colombian Caribbean coast). In Academic Magazine of Colombian Sciences 30 (115): 195 – 208. 2006.

[213] GENERAL MARITIME DIRECTORATE (DIMAR) and the CENTRE OF OCEANOGRAPHIC RESEARCH (CIOH). (Cartographic Atlas of the Oceans and Coasts of Colombia). 2nd edition. Publication 3007. Bogotá: 2005. 105 p.

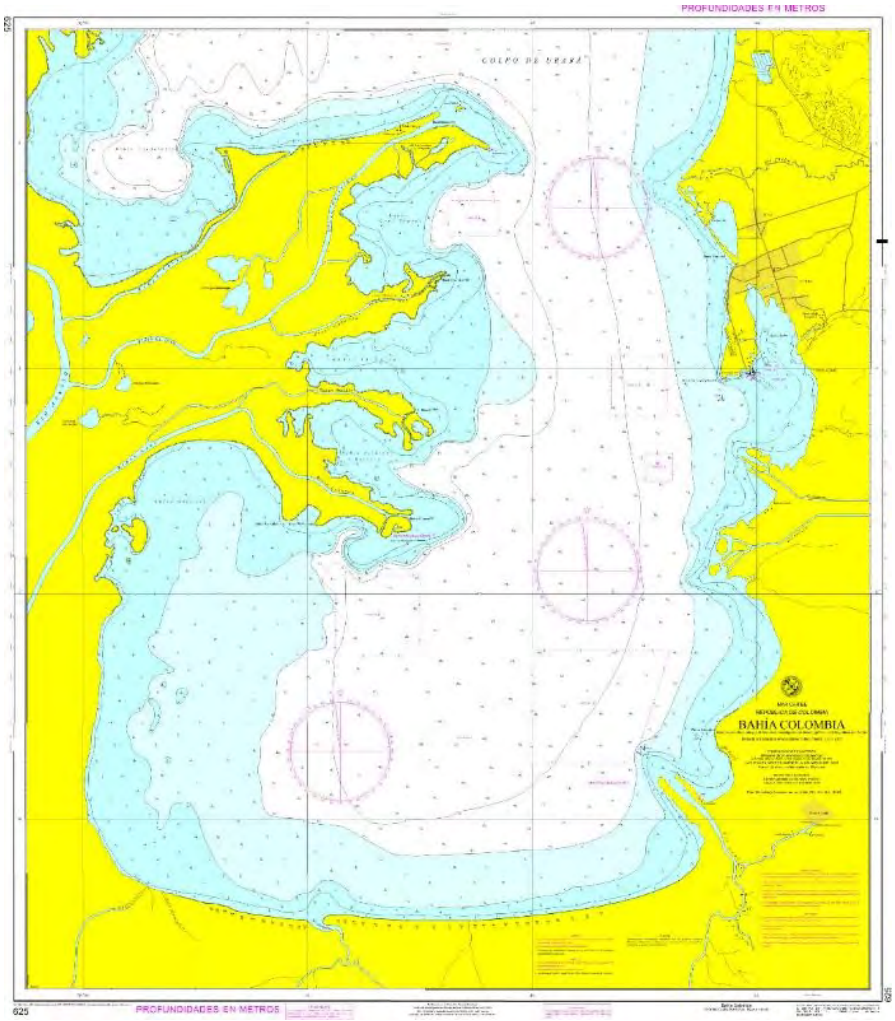


Figure 5.112 Nautical Chart 625[214]
Source: General Maritime Directorate

[214] GENERAL MARITIME DIRECTORATE (DIMAR) and the CENTRE OF OCEANOGRAPHIC RESEARCH (CIOH). (Cartographic Atlas of the Oceans and Coasts of Colombia). 2nd edition. Publication 3007. Bogotá: 2005. 105 p.

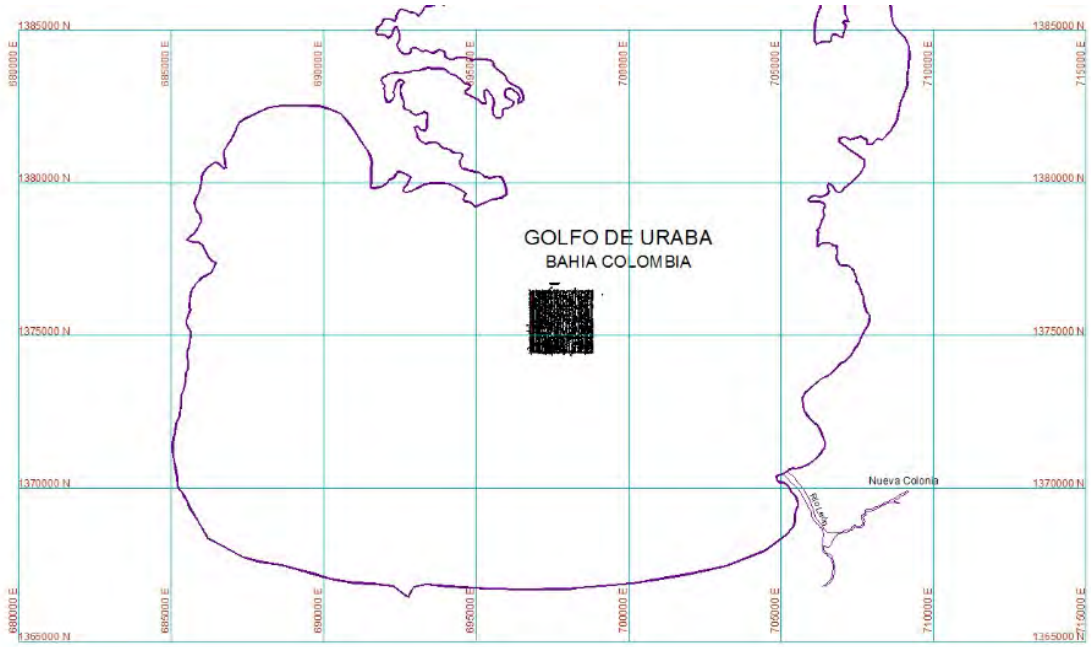


Figure 5.113 Detailed bathymetry of the landfill area, current conditions.
Source: *Aqua&Terra Consultores Asociados*.

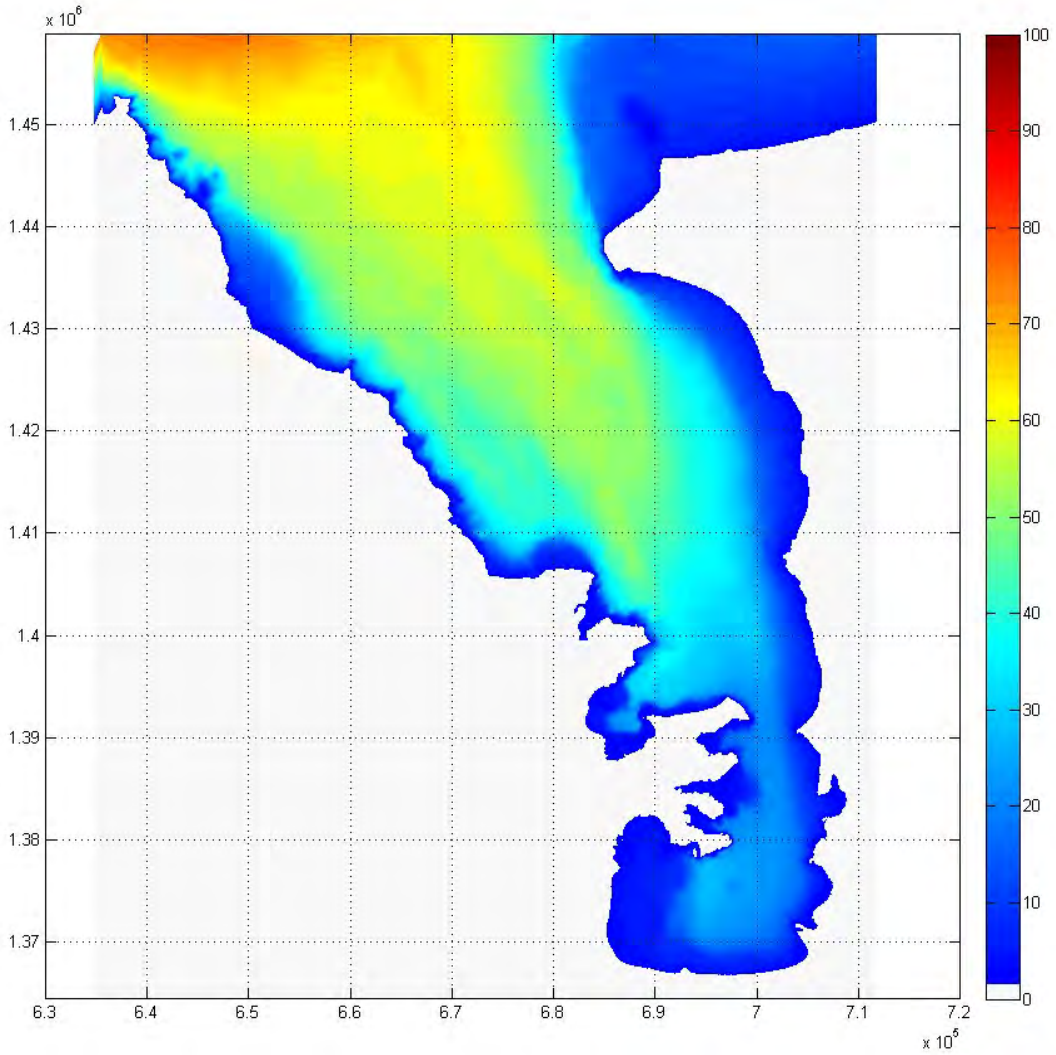


Figure 5.114 Initial General Interpolated Bathymetry
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

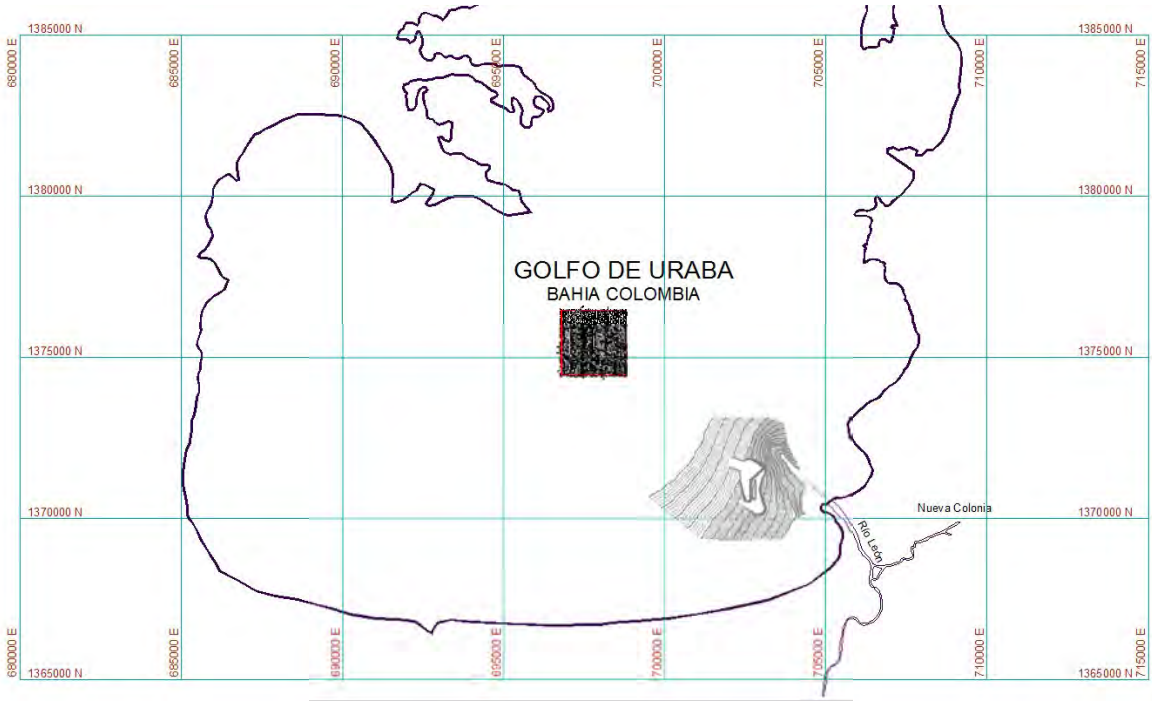


Figure 5.115 Detailed bathymetry of the design of dredging in the dock and landfill area
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

- Deep Water Swell

The area of study for the project is located in the Colombian Caribbean, in the Gulf of Urabá in the department of Antioquia (see Figure 5.116).

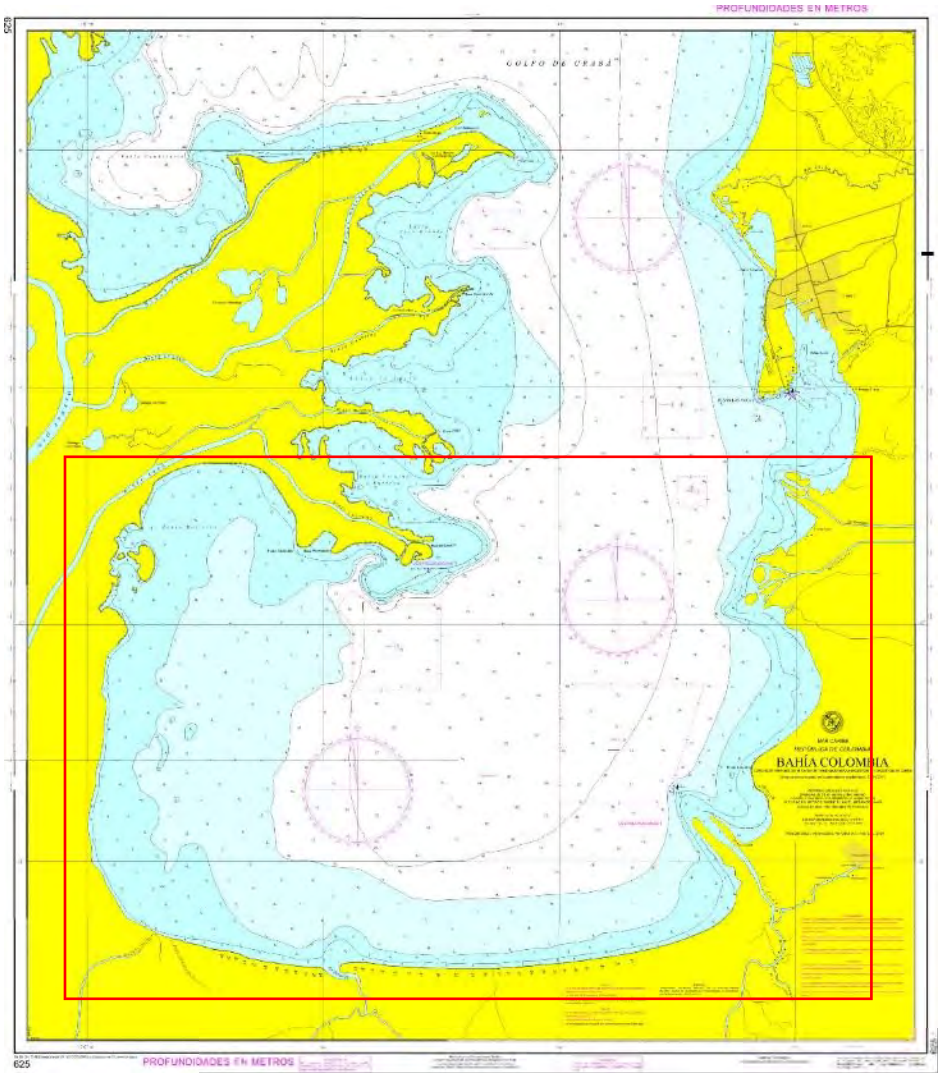


Figure 5.116 Detailed bathymetry of the design of dredging in the dock and landfill area
Source: CIOH (2005)[215], adapted by *Aqua&Terra Consultores Asociados S.A.S* (2015)

❖ Swell- Barranquilla Buoy

Instrumental swell data was obtained from the DIMAR buoy[216], located in Barranquilla at coordinates 11°9'41.0"N and 74°44'00"W (Figure 5.117), and when analyzed shows a set of data for significant wave height (Hs; see Figure 5.118). It

[215] GENERAL MARITIME DIRECTORATE (DIMAR) and the CENTRE OF OCEANOGRAPHIC RESEARCH (CIOH). Op. Cit.
[216] GENERAL MARITIME DIRECTORATE (DIMAR)

is important to underline how relevant a project like the one DIMAR (in conjunction with its research centers, the CIOH and the Pacific Pollution Control Center) has been developing is to the country. Thanks to the project, instrumental information that provides enhanced knowledge of the swell climate along both Colombian coasts has been available for several years. This work has required a great deal of resources and time, all of which is reflected in the quality of the information now available. This set of data has a record length from March 2006 to April 2009, at an hourly temporal resolution. It should be pointed out that while DIMAR has information up to 2014, *Aqua & Terra Consultores Asociados S.A.S* only has access to the previously mentioned data. The data set is not continuous as it contains various zero measurements, which appear as blank spaces in the set (see Figure 5.118). This makes it difficult to determine a pattern from the data set as there is no single continuous year of measurements, which makes it impossible to establish how wave heights vary throughout the year. From the graph, we can see that wave heights reach a maximum in the first months of the year and the lowest height occurs during the months of August and September.

Figure 5.117 Location of the Barranquilla buoy
Source: Google Earth™ (2013), modified by *Aqua&Terra Consultores Asociados S.A.S* (2015)

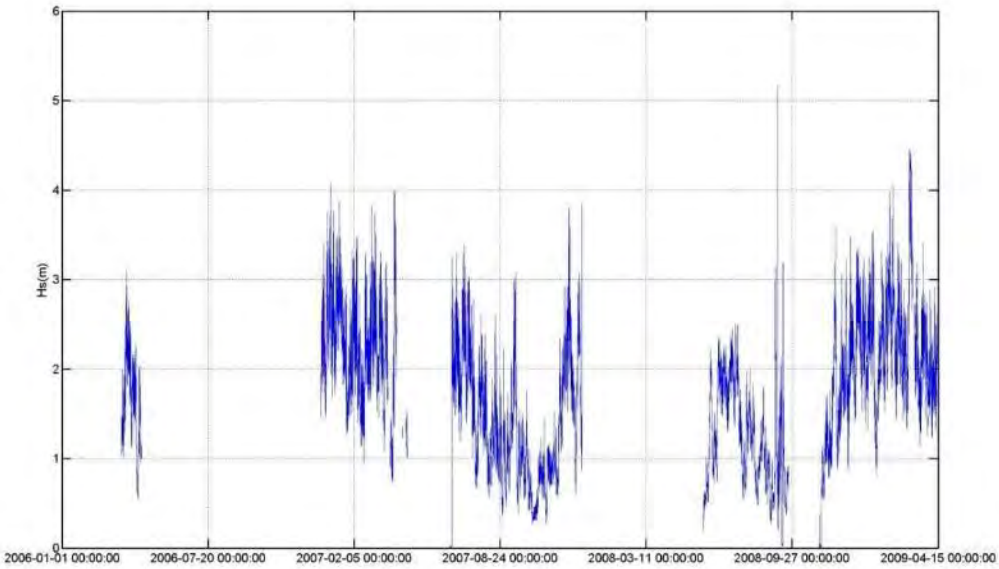


Figure 5.118 Hs data series from the Barranquilla buoy over the period between March 23rd, 2006 and April 20th 2009.
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

The wave height set, at an hourly temporal resolution, has a record length of over three years, starting in March 2006 and ending in April 2009. This set is not continuous as it includes various zero measurements, which can be observed in the blank spaces of the data set.

The fact that there is no continuous year of measurement makes it very difficult to identify a pattern from the data set, and the variations in wave height throughout the year cannot be determined. The graph does show that wave heights reach their maximum in the first months of the year, and are at a minimum in the months of August and September. This pattern, and the wind climatology of the area determine that the wave height pattern over the course of the year is bimodal in nature. Wave heights are at their maximum in the first months of the year when winds are strong, and in June and July when the *veranillo de San Juan* (Little summer of San Juan) takes place. Minimum wave heights occur in the months of March and April and between September and November, as during these months the winds in the Caribbean are less intense.

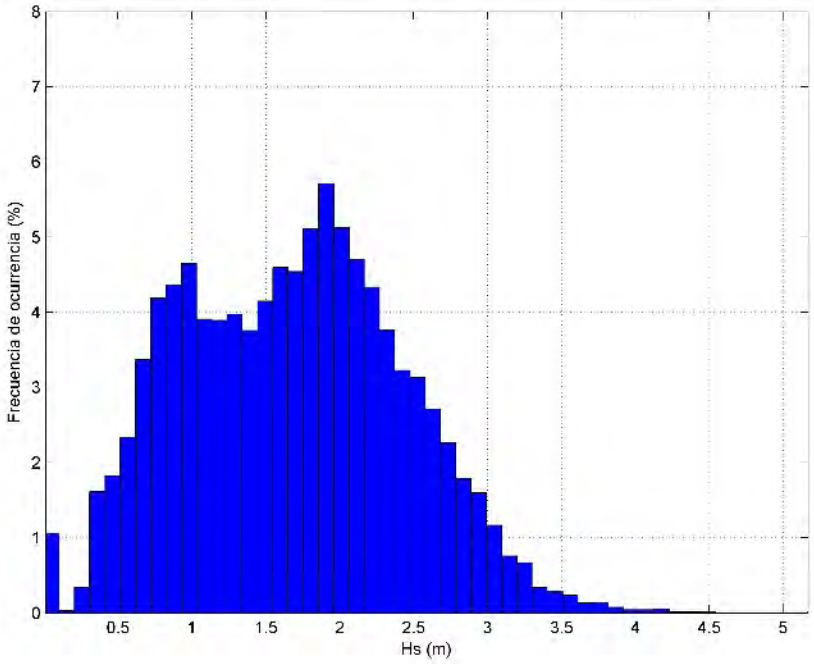


Figure 5.119 Histogram of Hs frequency, for the data obtained from the Barranquilla buoy.
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

The wave height values shown in the data set range from the order of centimeters Hs_{min}=0.30 m to maximum values that reach Hs_{max}= 4.5 m, with an average of Hs_{med}=1.67 m. The bimodal swell pattern can be observed in the graph, which identifies 2 swell peaks, the first around 1m in height and the second showing a wave height of approximately 2m.

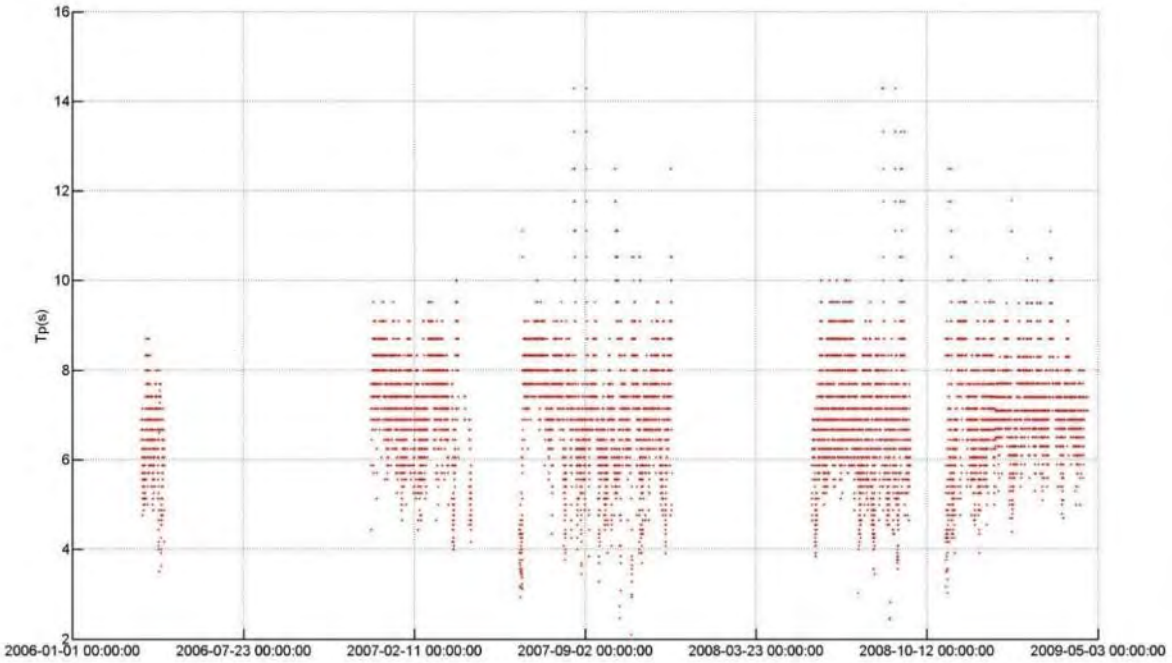


Figure 5.120 Tp data set from the Barranquilla buoy, over the period between March 23rd 2006 and April 20th 2009.
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

With regard to the periods, the data can be seen to be almost entirely grouped between 6 and 9 seconds. These values for the peak period are characteristic of a sea or local swell type, which is the predominate swell in the basin of the Colombian Caribbean.

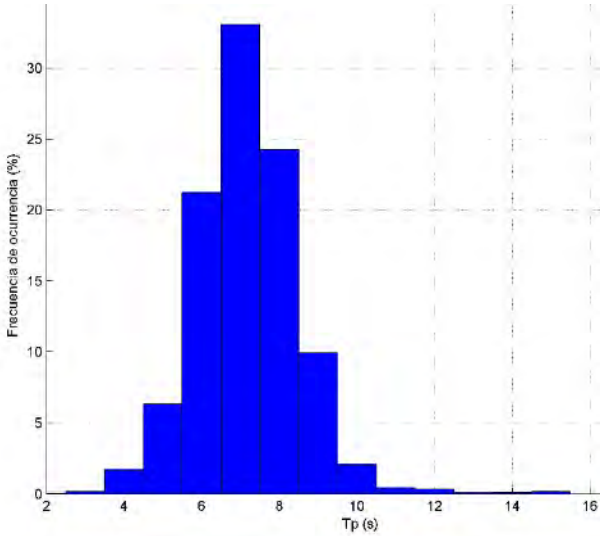


Figure 5.121 Tp frequency histogram for the data obtained from the Barranquilla buoy
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

The above graph shows the concentration of periods around 7 seconds long for the swell from the Barranquilla buoy, which is typical of sea or local swell types. The average for the periods is close to 7.1 seconds, and the longest periods are in the order of 11 to 12 seconds.

The circular swell graph shows the direction and height of waves at the Barranquilla buoy. Waves most frequently come from the north-east, representing 60% of the total amount, with around 25% coming from an east-northeast direction. The swell at the Barranquilla buoy can be seen to undergo a refraction phenomenon, produced by the ocean floor.

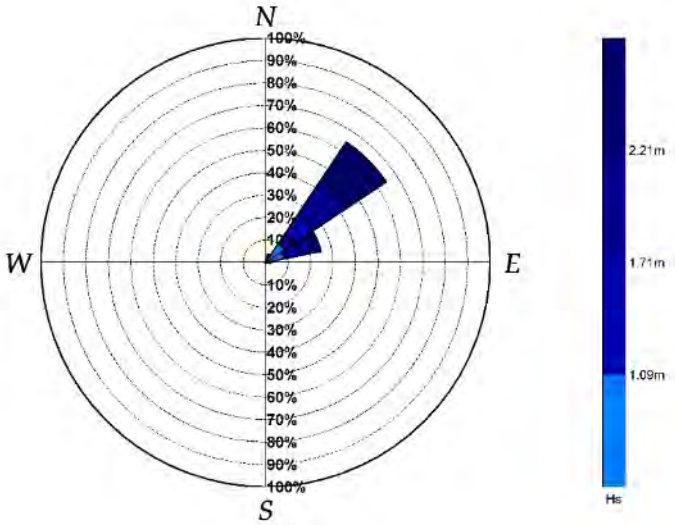


Figure 5.122 Circular swell graph
Source: *Aqua&Terra Consultores Asociados S.A.S* (2015)

❖ Meshes of Distribution

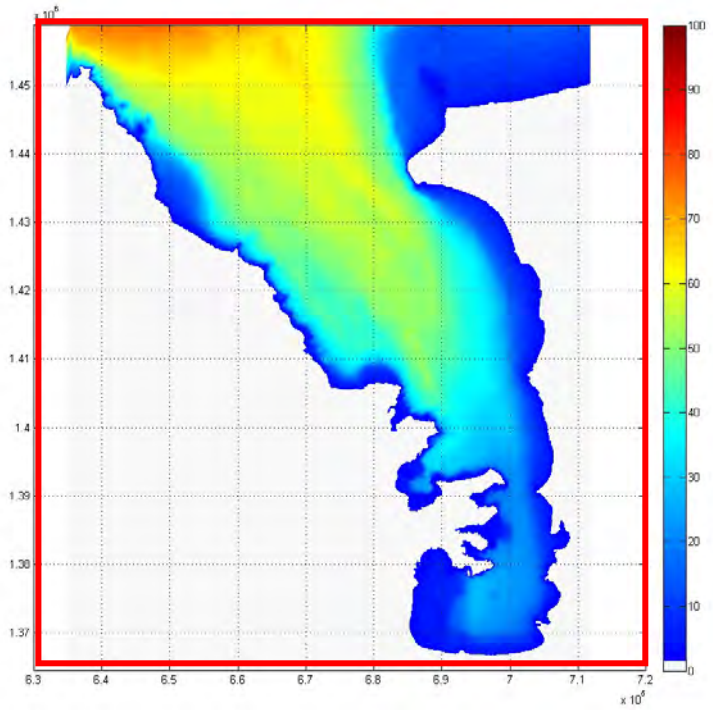
For the modeling, 2 types of meshes were prepared that allowed to define the general conditions of the study area and to know the wave dynamics in the area of interest. The bathymetry base (see Fig. No. 5.140) was used to feed the general mesh and the detail mesh of the condition without works; the bathymetry base and the bathymetry after the dumping of material from the dredging works of Puerto Bahía Colombia de Urabá, it was used to recreate the final condition of the proposed area as a landfill. In Table No. 5.52 and Fig. No. 5.141 you can see The Meshes used for the SWAN model. The general mesh of distribution has as purpose, to establish the conditions of waves in the contours of the detail mesh, for which reason, it does not need a very fine mesh pitch. The detail mesh, on the other hand,

needs a finer mesh, such that the zone and the incident energy coming from the waves can be characterized in the entire domain of interest.

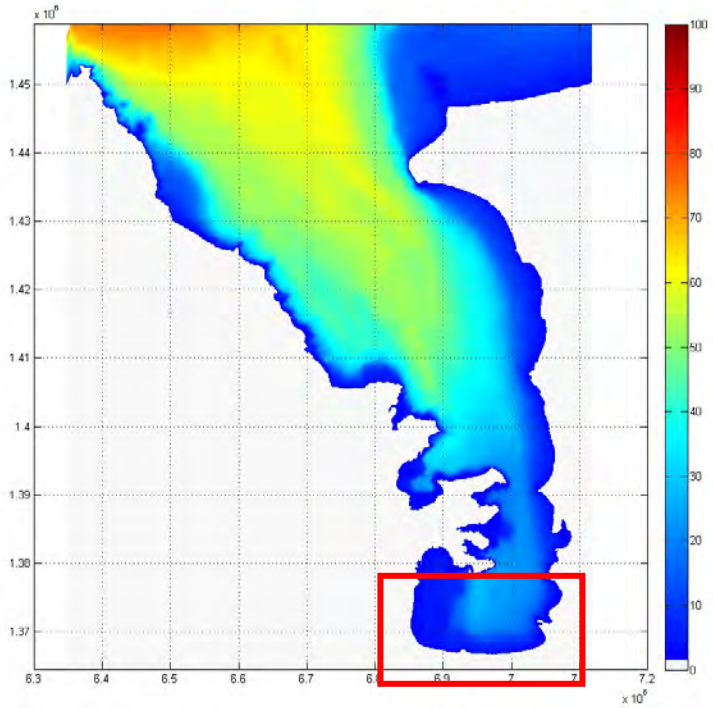
Table No. 5.47 Cases selected for the construction the average regime on site.

Name	Origin X, Origin Y	Angle	Cell Size (m)	[Nodes]
General	634810,1364570	0	130x160	600x 600
Detalle	683890,1365508	0	50x50	506x 312

Source: Aqua &Terra Consultores Asociados S.A.S, 2015



a)



b)

Figure No. 5.123 a) General Mesh and b) Detail used to reach the study area with model SWAN.

Source: Aqua &Terra Consultores Asociados S.A.S, 2015

❖ Results of wave distribution

After distributing each of the previously mentioned cases, we proceeded to perform the analysis of the wave dynamics in the study area, for each of the conditions analyzed, in order to establish the influence that the proposed landfill would have. Bahía Colombia de Urabá on coastal dynamics. In Annex 1 all the distributed cases are presented, with their corresponding graphics for the detail mesh. Below are the main results found for the most critical cases, and peak periods of 9 s, from a distribution direction of NNE, N and NNW, which are the directions that have the highest probability of occurrence for the zone.

- **Initial Condition – No material dumping and no dredging works – Deep Surf.**

Figure No. 5.143 shows the result of the wave distribution for the initial condition, is to say, without dumping of material from the dredging of Puerto Bahía Colombia de Urabá and without the dredging works, which has a wave height Significant of 3.25 m in indefinite depths, peak period of 9.0 s, tide level of 0.20 m and direction of propagation NNE, which is the predominant wave direction. The results are shown for the general mesh.

Figure No. 5.143 Case # 2 Hs = 3.25 m Tp = 9.0s Dir = NNE - Initial condition, no material spill, general mesh.
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

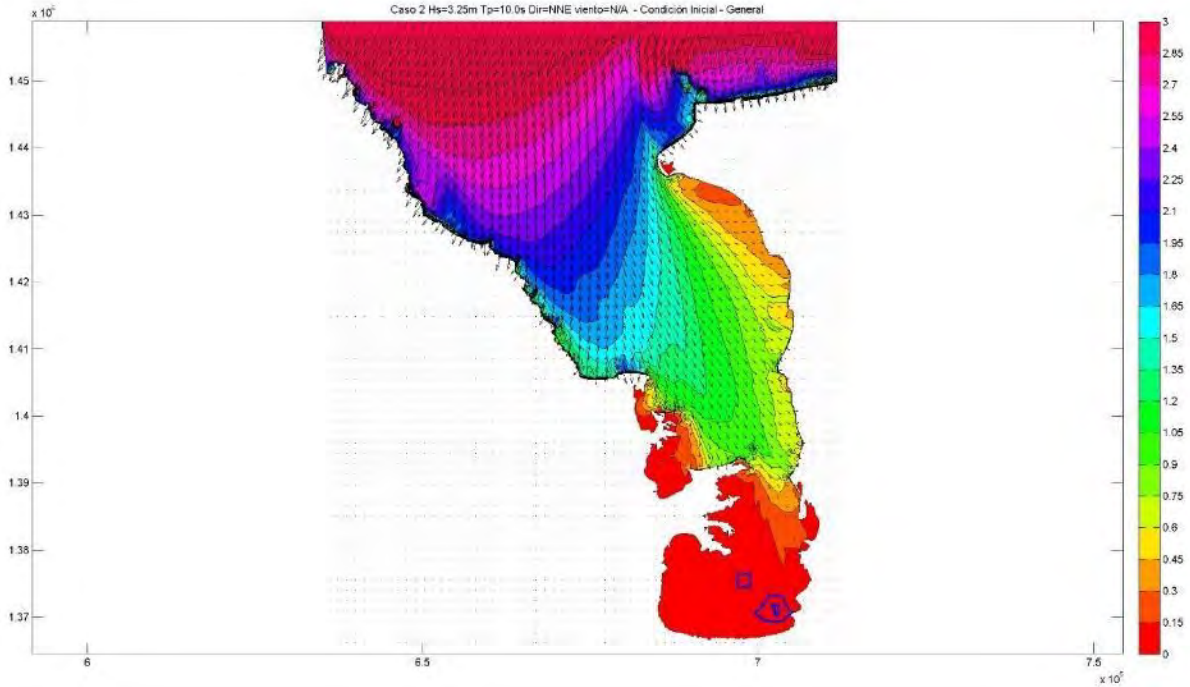


Figure No. 5.124 Case #2 Hs=3.25 m Tp=9.0s Dir=NNE – Initial Condition, without spillage of material, general mesh.
Source: Aqua &Terra Consultores Asociados S.A.S, 2015

From the previous figure it can be observed that the wave direction has been altered, due to the refraction and diffraction processes that the swell has experienced in its transition, from indefinite depths to shallower waters to the interior of the Gulf of Urabá. In this transition it can be observed that the energy of the waves is reduced by almost 70% due to the effect of the ocean floor and the semi-closed condition of

the Gulf of Urabá. Observing the results to the south of the gulf, it can be seen that the deltaic formation of the Atrato River enforces a control over the energy of the waves, dissipating the rest of the energy with which the waves come from deep waters.

From the previous figure it can be observed that the delta of the Atrato River prevents the wave energy from deep waters entering the interior of Bahía Colombia and therefore significant wave heights can be observed with a very low magnitude.

Figure No. 5.144 and Map MOD_LA_PTO_ANT_21 shows the result of the wave distribution for the initial condition, that is, without dumping material from the dredging of Puerto Bahía Colombia de Urabá, which has a significant wave height of 3.25 m in indefinite depths, peak period of 9.0 s, tide level of 0.20 m and distribution direction NNE, which is the predominant wave direction. The results are shown for the detail mesh.

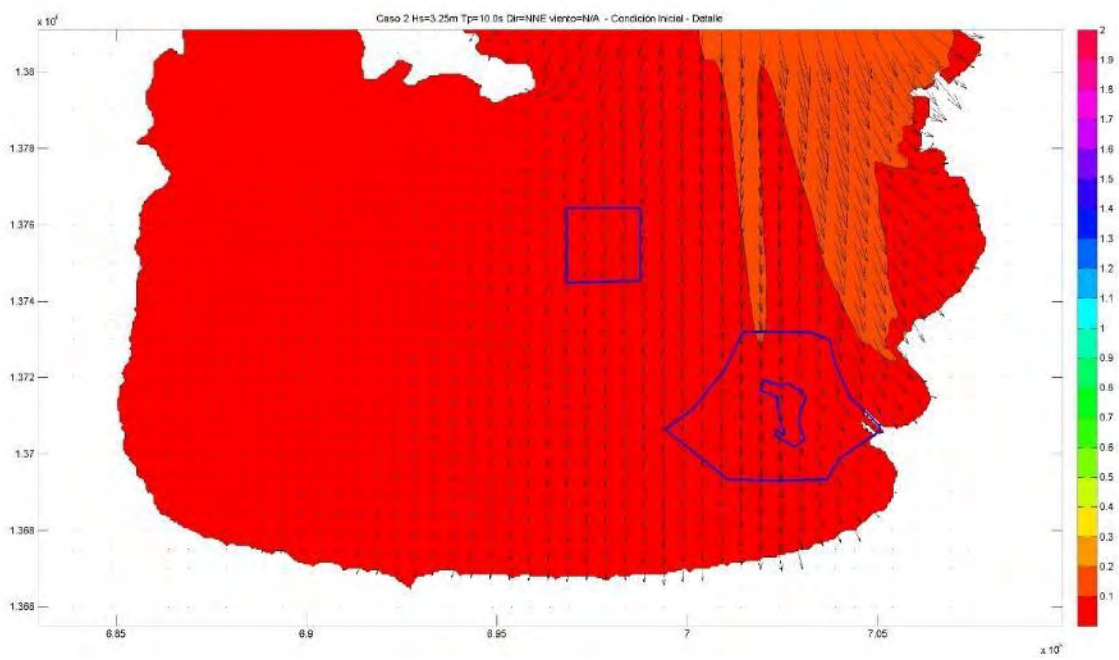


Figure No. 5.125 Case #2 Hs=3.25m Tp=9.0s Dir=NNE – Initial condition, no material discharge, detail mesh. Deep Surf ..

Source: Aqua &Terra Consultores Asociados S.A.S, 2015

From this figure you can see the effect that the delta of the Atrato River has on the energy of the waves. For this case, the wave in deep waters had a wave height of 3.25 m and when passing the delta formation this is less than 0.25 m, which represents a 97% decrease in the energy it had before entering the Gulf of Urabá

In the area of the landfill and the area of the dredging works can be seen a wave height ranging between 0.05 and 0.10 m, with a direction that is of the order of N10 ° E. These wave conditions prove the theory that in gulfs and bays the local swell may be more important than the deep swell.

The other cases distributed by the deep swell can be seen in ANNEX A.

In addition, due to the control exercised by the delta of the Atrato River on the oceanographic conditions of Bahía Colombia, an analysis of the swell produced inside the Gulf of Urabá was carried out, for which the study of the winds that had occurred in the sector.

- **Initial Condition – No material dumping – Local Surf.**

Figure. No. 5.145 shows the result of the wave distribution for the initial condition, that is, without dumping of material from the dredging of Puerto Bahía Colombia de Urabá and without the dredging of the Darsena, which has a wind magnitude of 11.0 m / s, tide level of 0.20 m and direction of distribution N, which is the predominant direction of the wind. The results are shown for the general mesh.

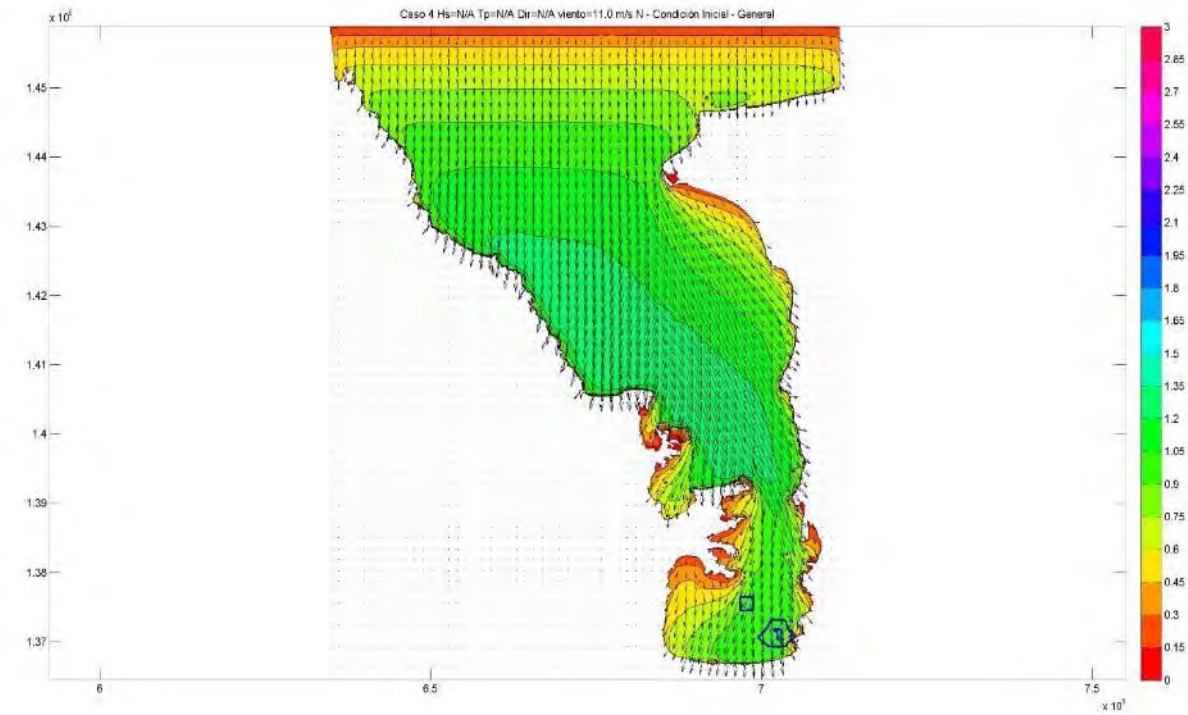


Figure No. 5.126 Case #7 Magnitude of the wind =11.0m/s, Direction=N – Initial Condition, without projects, General mesh. Local surf.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

In the previous figure it can be observed the behavior of the local swell (or produced by the wind conditions), to the interior of the Gulf of Urabá and Bahía Colombia. In this case, the most frequent wind condition for the study area was distributed, which is that of the north.

The figure shows how in the north of the gulf the waves start to develop and how they reach their greatest magnitude in the west margin before the delta of the river Atrato. Part of the energy of the swells that are generated in the north of the Gulf enter Colombia Bay and join with those generated in this to continue on its way to the sector where the building sites of Puerto Bahía Colombia de Urabá are located in the area of the landfill you can see a wave size close to 1.0 m in height and an NNE direction, while for the port area the wave height is 1.1m from the north.

In Figure No. 5.146 and map MOD_LA_PTO_ANT_22 it shows the result of the wave distribution for the initial condition, that is to say, without dumping of material

from the dredging of Puerto Bahía Colombia de Urabá, which has a wind magnitude of 11.0 m / s, tide level of 0.20 m and distribution direction N, which is the main direction of the wind. The results are shown in the detailed mesh.

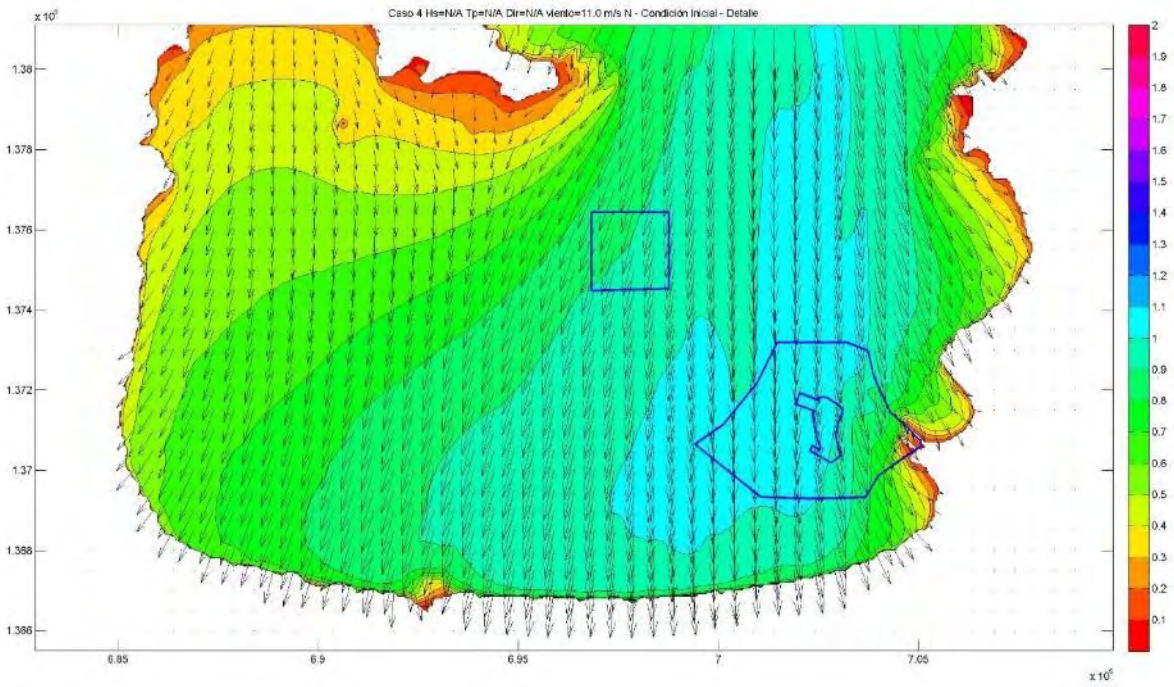


Figure No. 5.127 Case #4 Magnitude of the wind =11.0m/s, Direction =N – Initial Condition , without projects , Detail mesh. Local Surf.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

From the previous figure you can see how the waves, generated by the most predominant condition of the wind inside the gulf, are developing from north to south, reaching higher altitude values towards the south side, due to having higher FETCH. In the site where the material dredging from Puerto Bahía Colombia de Urabá material is proposed, it varies between 0.90 and 1.00 m, with an NNE direction, while in the sector of the building site of Puerto Bahía Colombia de Urabá it can be observed that the magnitude varies between 1.00 and 1.10 m, with a north direction.

- **Final Condition – With projects – Deep surf.**

In Figure No. 5.147 it shows the result of wave distribution for the Final condition, that is to say, with dumping of material from the dredging of Puerto Bahía Colombia de Urabá, which has a significant wave height of 3.25 m in depths undefined, peak period of 9.0 s, tide level of 0.20 m and distribution direction NNE, which is the predominant wave direction. The results are shown for the general mesh.

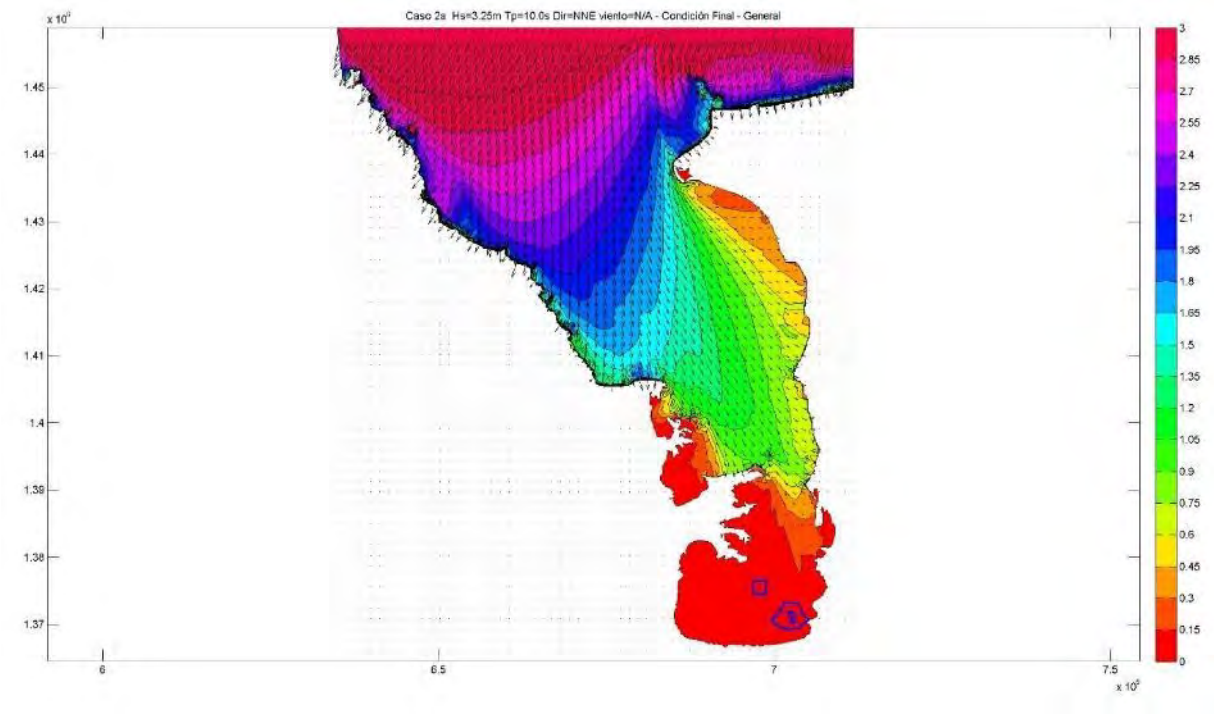


Figure No. 5.128 Case #2a Hs=3.25m Tp=9.0s Dir=NNE – Final Condition, With projects, general mesh.

Source: Aqua &Terra Consultores Asociados S.A.S, 2015

From the previous figure it shows a behavior like that distributed for the condition in which there was no dumping of material from the dredging works of Puerto Bahía Colombia de Urabá, nor the dredging of the dock. A modified wave is observed, both in magnitude and direction, by the phenomena of refraction and diffraction that the ocean floor generates on it.

The effect of the deltaic formation of the Atrato River is observed, which dissipates most of the energy with which the swell reaches this sector. It is appreciated as in the Colombia bay, the waves coming from deep waters have no incidence.

Figure No. 5.148 and map MOD_LA_PTO_ANT_23 shows the result of the wave propagation for the Final condition, that is, with dumping of material from the dredging of Puerto Bahía Colombia de Urabá, which has a significant wave height of 3.40 m in indefinite depths, peak period of 9.0 s, tide level of 0.20 m and distribution direction NNE, which is the predominant wave direction. The results are shown for the detail mesh.

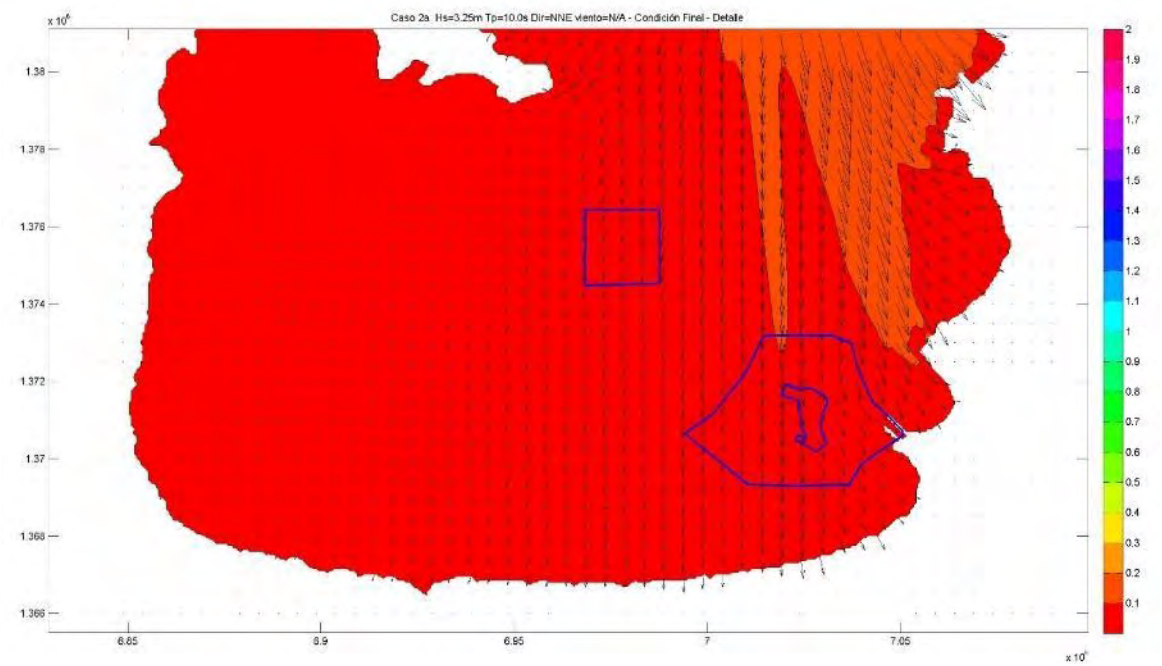


Figure No. 5.129 Case #2a Hs=3.25m Tp=9.0s Dir=NNE – Final Condition, With projects, detail mesh. Deep surf.

Source: Aqua&Terra Consultores Asociados S.A.S, 2015

From the previous figure it can be seen that the interior of Bahía Colombia, the background swell is completely dissipated and that all the energy it had when entering the Gulf of Urabá, has been dissipating in the entire journey it made to reach the area of interest. In the sector that is proposed for the landfill of the material that comes from the dredging works of Puerto Bahía Colombia de Urabá, a wave height is observed that varies between 0.05 and 0.10 meters, with a direction close to N10

° E, while in the area of dredging the waves are less than 0.10 m with a north direction.

- **Final Condition – with material dumping – Local Surf.**

Figure No. 5.149 shows the result of the wave distribution for the Initial condition, that is to say, without dumping of material from the dredging of Puerto Bahía Colombia de Urabá, which has a wind magnitude of 11.0 m / s, level of tide of 0.20 m and direction of distribution N, which is the predominant direction of the wind. The results are shown for the general mesh.

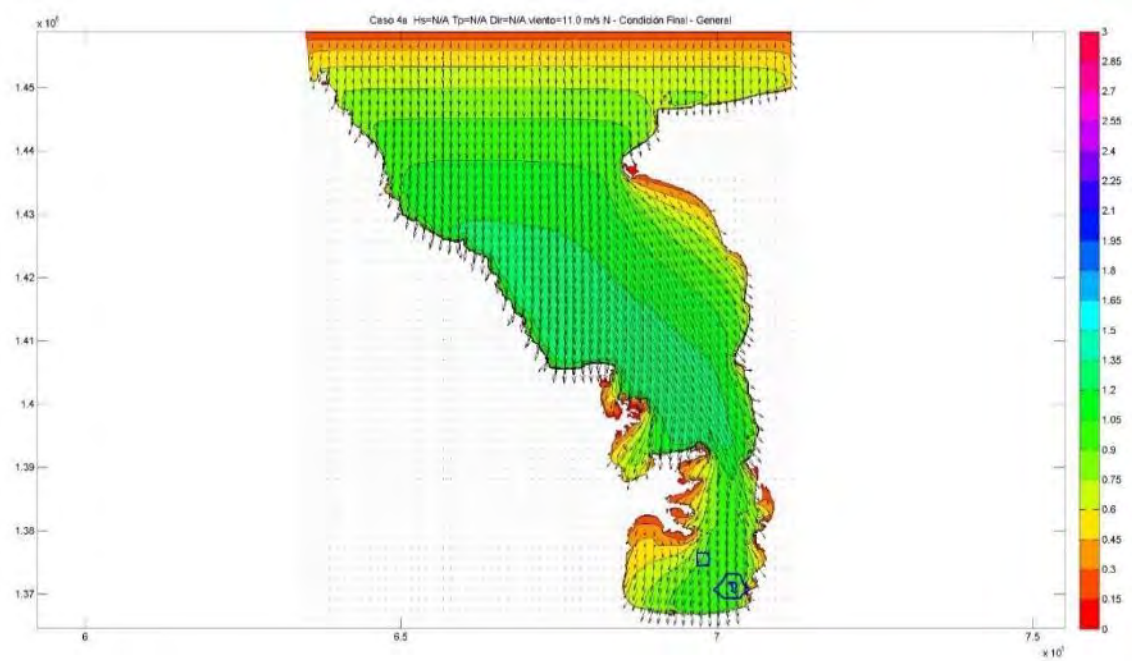


Figure No. 5.130 Case #4a Magnitude of the wind =11.0m/s, Direction=ENE –Final Condition, with projects, General mesh . Local surf.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

From this figure it can be observed that in the interior of the Colombia bay, the local (or wind) waves are much more significant than the waves that distribute from deep water. Here, you can see a swell that was developed by wind to the interior of the Gulf of Urabá, which has much larger magnitudes in the sector where the dredging of the maneuvering dock is considered, due to having a higher FETCH. In the sector that is proposed as a landfill, we can see a wave that has a magnitude close to 0.90

m and an N22.5 ° E direction and in the dredging sector there is a wave height of 1.1 m with a north direction. Broadly we can see a behavior similar to those presented in the distributions of the initial condition.

In Figure No. 5.150 yy map MOD_LA_PTO_ANT_24 it shows the result of the wave distribution for the Final condition, that is, with the dumping of material from the dredging of Puerto Bahía Colombia de Urabá, which has a wind magnitude of 11.0 m / s, tide level of 0.20 m and distribution direction N, which is the predominant direction of the wind. The results are shown in the detailed mesh

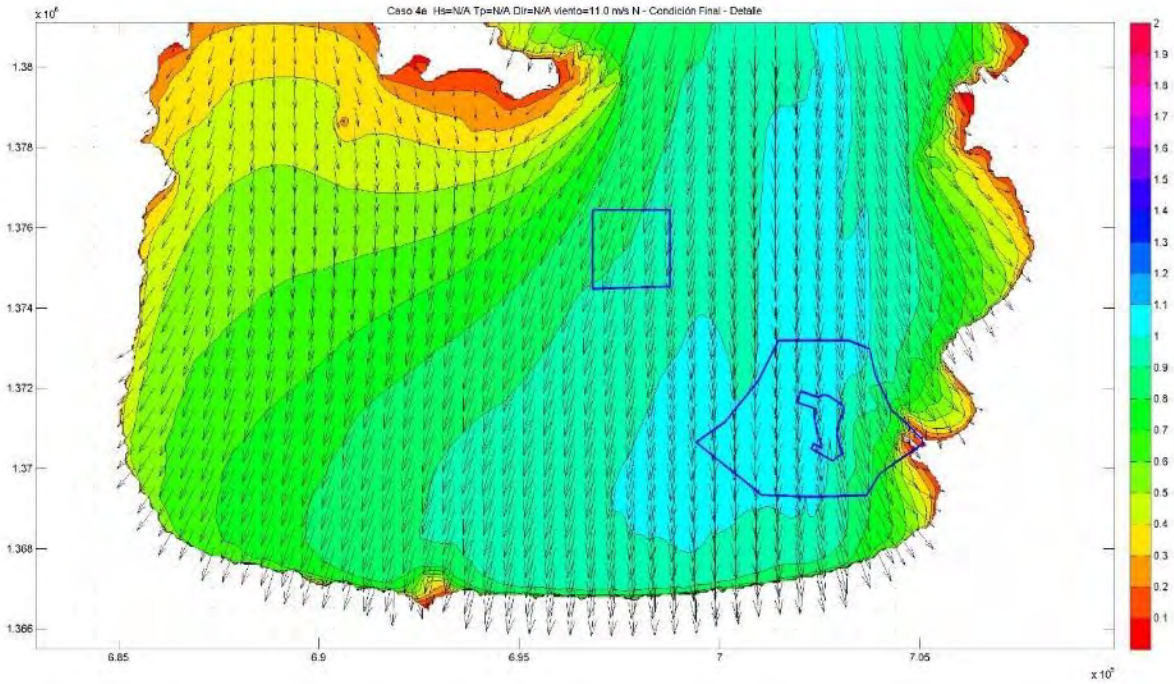


Figure No. 5.131 Case #4a Magnitude of the wind=11.0m/s, Direction=N –Final condition, with projects, detail mesh. Local surf.
Source: Aqua &Terra Consultores Asociados S.A.S, 2015

From the previous figure you can see how the waves, generated by the most predominant wind condition in the interior of the gulf, develop from north to south, reaching higher altitude values towards the south, due to having higher FETCH. In the site where the material dredging from Puerto Bahía Colombia de Urabá material

is proposed, it varies between 0.80 and 1.00 m, with an NNE direction, while in the dredging area the waves have a wave height of 1.10 m with a north direction.

- **Differences between the different condition**

In Figure No. 5.151 the differences between the initial condition and the final condition of the swell case number 2 are shown, which have an Hs = 3.25m, Tp = 9s and NNE direction. This is done to establish the impact of the dumping of material from the dredging building sites of Puerto Bahía Colombia de Urabá on the coastal dynamics of Colombia Bay, both for the deep waves and for the local waves.

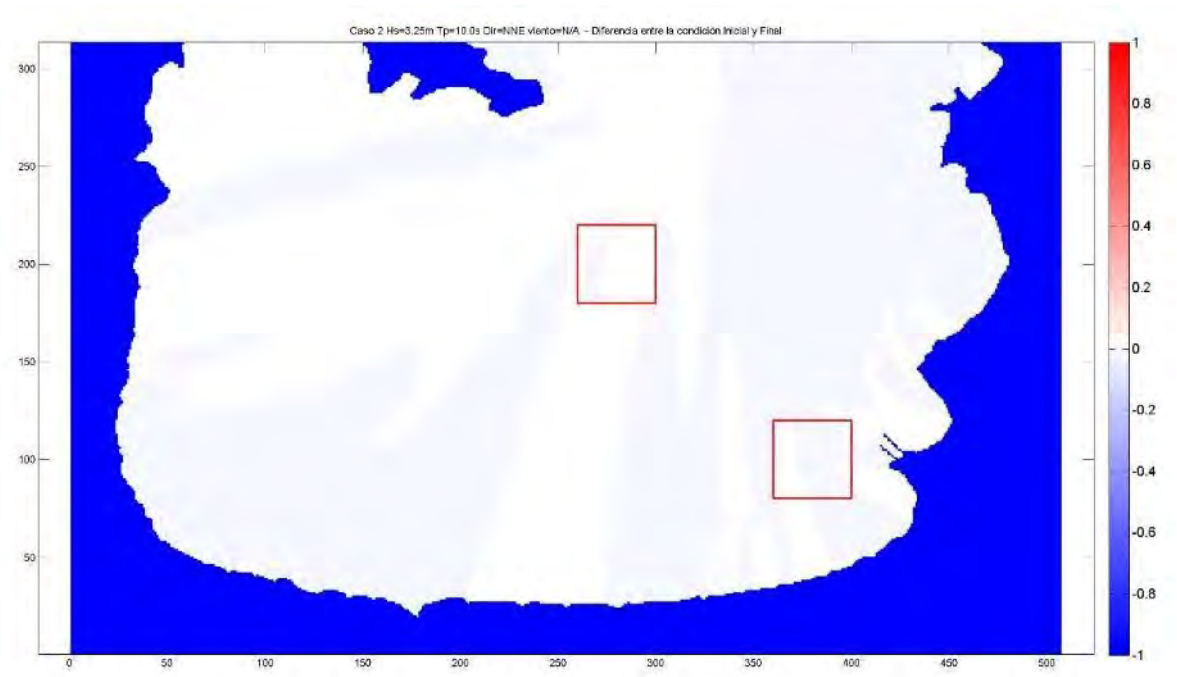


Figure No. 5.132 Wave height differences between the initial condition and the final condition, for that matter #2 Hs=3.25m Tp=9.0s Dir=NNE.
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

From the former figure it can be seen that in the area that is proposed as a landfill for the material coming from the dredging building sites of Puerto Bahía Colombia de Urabá, the wave height conditions for deep waves, both in the landfill and in the surrounding areas, are not affected by the dumping of this material. You can see how the difference between the initial condition and the final condition does not exceed 1 centimeter in height. It is also important to point out that in the previous

graph there is a small numerical noise of the order of millimeters that is not representative for the analyzes that are being carried out, allowing to conclude with total certainty that the building sites do not affect the dynamics in the area

In Figure No. 5.152 it shows the differences between the initial condition and the final condition of the wave case number 4, which have a wind magnitude = 11.0 m / s and address N. The above is done, to establish What impact does the dumping of material from the dredging works of Puerto Bahía Colombia de Urabá have on the coastal dynamics of Colombia Bay.

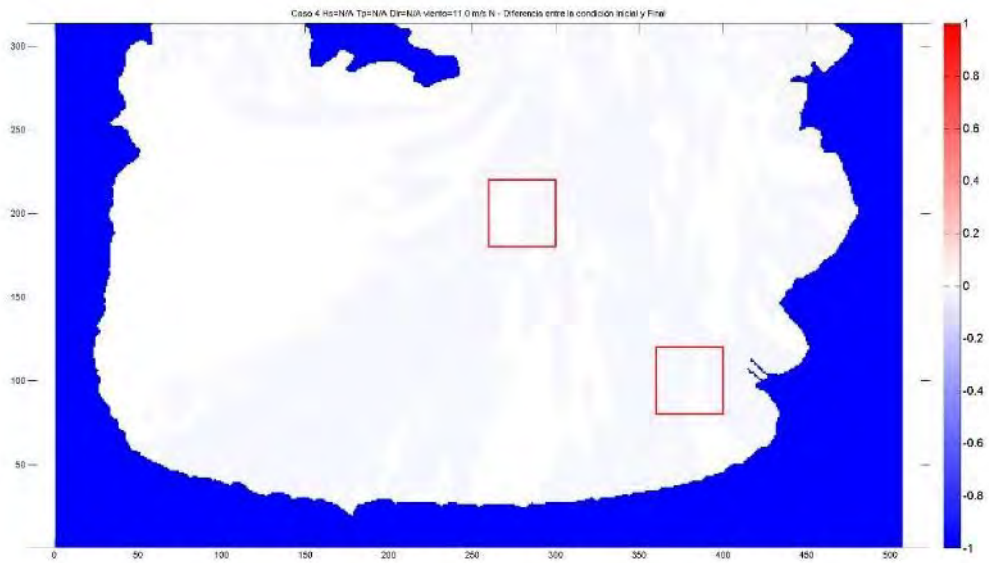
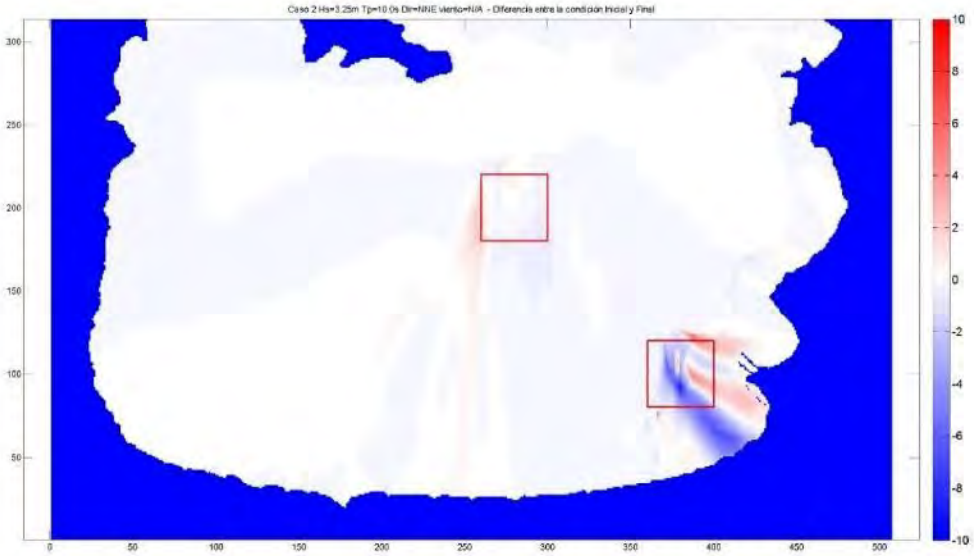


Figure No. 5.133 Wave height differences between the initial condition and the final condition, for that matter #4 Magnitude of the wind=11.0m/s, Direction=N.
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

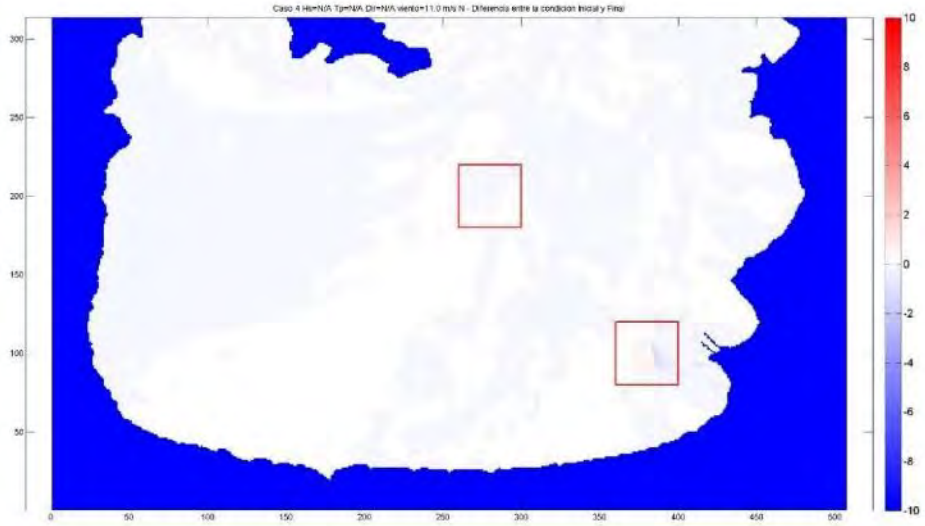
From the previous figure you can see a behavior similar to that shown for the deep swell. The difference between the initial and final condition of the landfill area and surrounding areas is practically zero.

The figures for the other conditions can be seen in Annex A.

In terms of wave directions, the following figure shows a comparison between the initial condition and the final condition of the Colombia bay for the deep swell and the local swell. The color scale denotes the directional difference in degrees.



(a) Deep surf



(b) Local surf

Figure No. 5.134 Wave direction differences between the current condition and future condition.

Source: Aqua&Terra Consultores Asociados S.A.S, 2015

From the previous figure we can observe the changes that occur in terms of the direction of the waves, due to the effect of the dumping of material and the dredging

of the dock, in the study area. It can be seen that the differences between the initial condition and the final condition only vary between -1 ° and 1 °, just after the proposed discharge. In the port sector, it can be seen that the change in direction is a little more marked (around 4 to 5 degrees), for the deep waves, due to the fact that during the wave period it is felt more on the ocean floor. These small differences are due to the fact that the proposed dumping does not produce a hard point that generates diffraction of the waves, nor a significant change at depth level in relation to the periods that occur in the area, so the ocean floor does not generate refraction processes that modify the direction of the waves. It is important to consider that the waves in nature also have a degree of angular dispersion that can be like the magnitudes obtained here, therefore it cannot be considered that these changes represent a great influence on the current dynamics. The main difference is in the deep waves, but this is the least representative of the study area, besides being the one that presents the greatest angular dispersion in a natural way. From the previous figure it can be noted that the wave direction that is present at this time in the study area will be maintained even with the dumping of dredged material from the building sites of Puerto Bahía Colombia de Urabá.

As a conclusion of this study, it can be said that the dumping proposed by Aqua & Terra for the dumping of material from Puerto Bahía Colombia de Urabá has no effect on the important coastal dynamics and this can be observed by the fact that wave patterns have not suffered significant changes in the study area, neither in magnitude nor in direction.

- **Analysis of the impact on coastline dynamics because of the construction of the pier or offshore platform.**

With the main purpose of evaluating the impact that the offshore pier has on coastal dynamics, a model has been developed, making use of wave penetration software. The tool used for this modeling is Xbeach, this is a numerical model of free access, which simulates hydrodynamic processes and morphodynamics and impacts of sand beaches in domains of kilometers and temporary storms.

This model includes hydrodynamic processes of wave transformation: refraction, breakage, distribution and dissipation, run-up and flood. In the same way it allows to include the impact of structures and vegetation. This model allows having a computational advantage from two modeling modules (hydrostatic and non-hydrostatic) that allow you to optimize computational time.

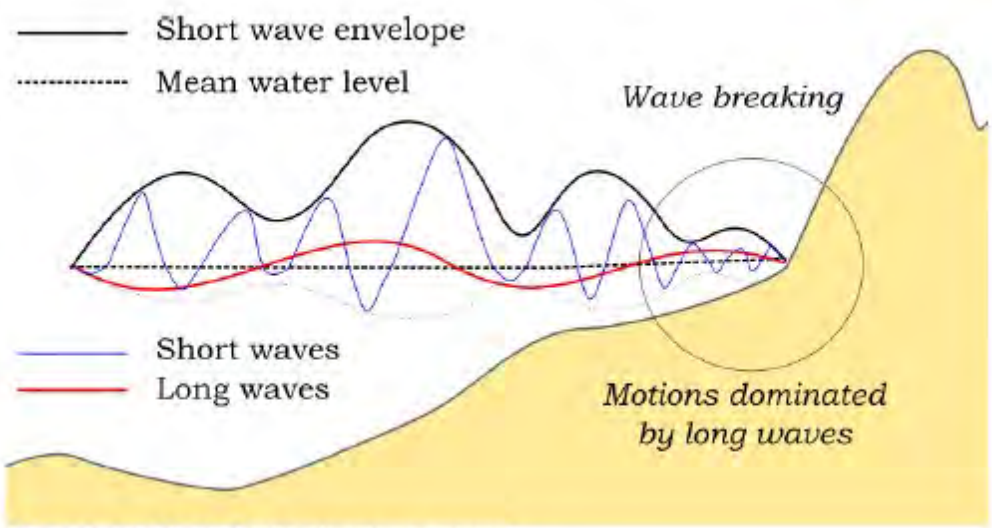


Figure 2.3 Principle sketch of the relevant wave processes

Figure No. 5.135. Main wave modeling processes of Xbeach.
Source: Xbeach Manual, 2015.[217]

This model is integrated into the water column (Type 2DH) and is supported by the Delft 3D software platform for the assembly of the domain, bathymetry and mesh.

For the analysis of the impact of offshore sites on coastal dynamics, the following conditions have been defined:

• Condition before projects

• Condition after the projects that includes: dredging projects and the configuration of offshore quay piles (phase 1) according to the dimensioning established in the description of this project.

[217] Deltares, Xbeach Manual, 2015.

• Establish the wave condition that has the greatest impact on coastal dynamics. This scenario will be defined by waves with peak periods of more than 5 seconds, which have the greatest transport capacity and therefore affect the coastline.

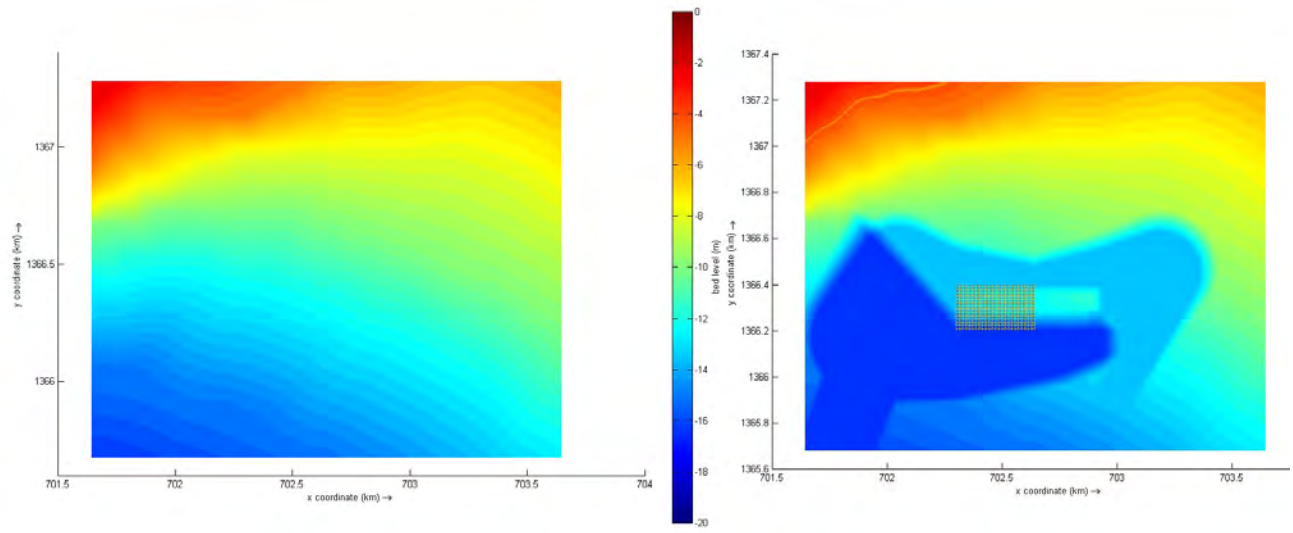


Figure No. 5.136. Bathymetries and domain before and after projects.
Source: Aqua & Terra Consultores

From the field campaign carried out by the National University in 2010 and determined the density function of the distribution, a range of probability of certainty of the data of 95% has been established (this corresponds to the average more or less twice the standard deviation). To obtain the most critical condition, the maximum values of the corrected series were defined, obtaining: significant wave height (Hs) of 0.65 m and peak period (Tp) of 5 s.

The dispersion of the waves defined scenario has been established for condition before and after the projects, in this way the effects of wave dispersion in the study area can be compared.

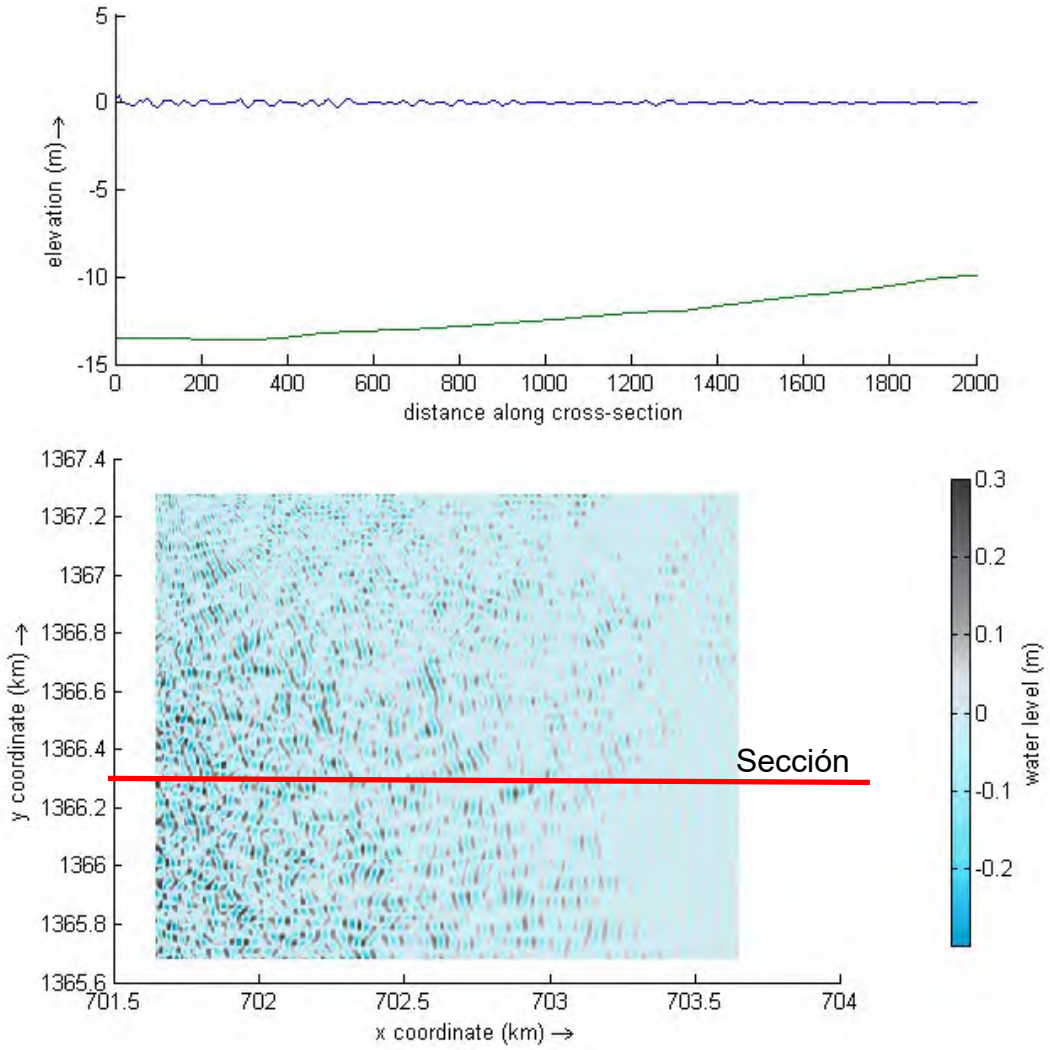


Figure No. 5.137. Distribution of the swell condition before projects.
Source: Aqua & Terra Consultores

Figure No. 5.156 allows us to distinguish the refraction and wave diffraction processes by the variation of the seabed, where the wave front disperses towards the left bank by refraction (shore that corresponds to the right bank of the Leon River).

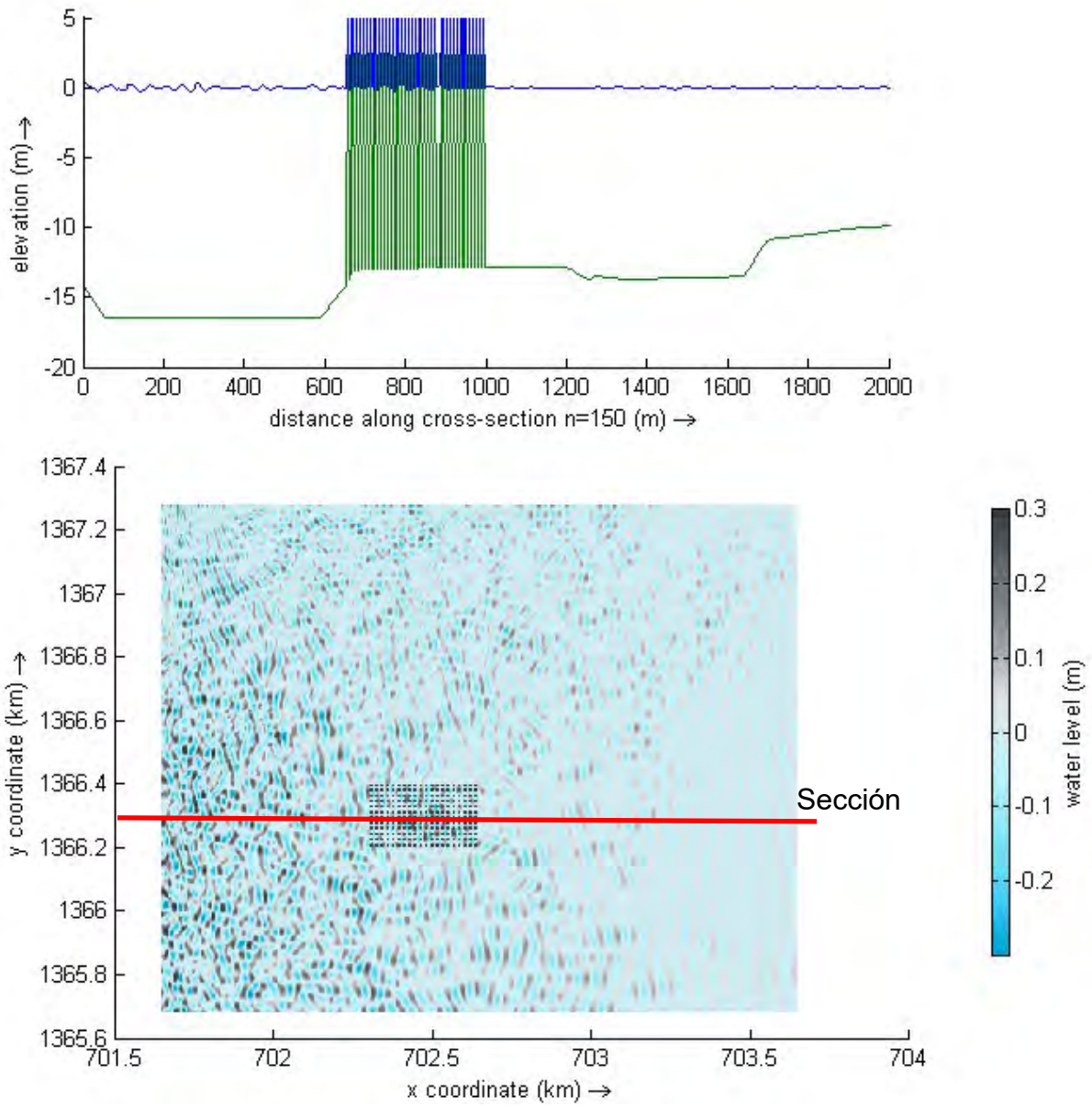


Figure No. 5.138. Distribution of the waves with piles and bottom changes by dredging.
Source: Aqua & Terra Consultores

Figure No. 5.157 allows us to evaluate the impact of the projects in Bahía Colombia, where it is evident how the piles and the change of the ground generate a low

alteration in the hydrodynamics of the area. Initially, the surf south of the pier presents a marked wave diffraction process. Process that has a predominant extension of approximately 300 to 250 m. However, continuing, it is distinguished both in profile and in level as this effect fades and the waves recover in less than 500 meters south of the bay. As in Figure No. 5.156, there is a high wave dissipation in the southern area

From what was described previously, it is concluded that off shore projects do not generate an impact on coastal dynamics and the impact on the waves is local and is recovered in the process of distribution south of the pier.

- Ruptured currents

As it is known, wave breaking generates additional currents that are manifested through the radiation tensor, which must be estimated to evaluate the effects that the project would have on the coast surrounding it. In order to know its behavior, it is necessary to use a model that determines the wave's radiation tensor from the results of height and wave incidence obtained in the distribution, calculating the field of currents and levels due to said radiation tensors. To achieve this, the SWAN model was coupled to the flow module of the DELFT 3D model. The description of the DELFT 3D model is shown below.

- **Description of the delft 3d model**

Delft3D is an integrated modeling system of flow and transport oriented to the aquatic environment that solves the Navier-Stokes equations for shallow waters with the hypothesis of hydrostatic pressures and the Boussinesq approach. The mathematical formulations included in the model allow to take into account the following physical phenomena.

- Effects of the rotation of the Earth (Coriolis force).

- Baroclinic effects.

- Masses of induced turbulence and moment flows (turbulent closure models).

- Transportation of salinity, temperature and other conservative substances.

- Forces of tide in open contours.

- Spatial and temporal variations of the tangential tension of the wind on the surface of the water body.

- Spatial variations of the tangential tension in the background.

- Spatial and temporal variations of atmospheric pressure on the surface.

- Temporary variation of sources and drains (i.e. discharges in rivers).

- Flooding and drying of low tides.

- Heat flows.

- Effect of the waves.

The equations of government are the following:

Continuity equation

$$\frac{\partial \zeta}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)u\sqrt{G_{\eta\eta}}\right]}{\partial \xi}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)v\sqrt{G_{\xi\xi}}\right]}{\partial \eta}+\frac{\partial \omega}{\partial \sigma}=H\left(q_{in}-q_{out}\right)+P+E$$

Where, u, v y w are the components of velocity in the directions ξ, η y σ, respectively, qin, qout are sources and a drain of water per unit volume [1 / s], $\sqrt{G_{\eta\eta}}$ and $\sqrt{G_{\xi\xi}}$ are conversion coefficients between curvilinear and orthogonal coordinates and P and E are source terms of precipitation and evaporation, respectively, that can act on the surface.

Equation of conservation of momentum

The equations of conservation of the momentum in the directions ξ and η are:

$$\frac{\partial u}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial u}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial u}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial u}{\partial \sigma}-\frac{v^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}+\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}-fv=$$
$$-\frac{1}{\rho_0\sqrt{G_{\xi\xi}}}P_\xi+\frac{1}{\sqrt{G_{\xi\xi}}}\frac{\partial\tau_{\xi\xi}}{\partial \xi}+\frac{1}{\sqrt{G_{\eta\eta}}}\frac{\partial\tau_{\xi\eta}}{\partial \eta}+\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial u}{\partial \sigma}\right)+M_\xi$$

$$\frac{\partial v}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial v}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial v}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial v}{\partial \sigma}-\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}+\frac{u^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}+fu=$$
$$-\frac{1}{\rho_0\sqrt{G_{\eta\eta}}}P_\eta+\frac{1}{\sqrt{G_{\xi\xi}}}\frac{\partial\tau_{\eta\xi}}{\partial \xi}+\frac{1}{\sqrt{G_{\eta\eta}}}\frac{\partial\tau_{\eta\eta}}{\partial \eta}+\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial v}{\partial \sigma}\right)+M_\eta$$

Where Pξ and Pη represent the pressure gradients, $\tau_{\xi\xi}$, $\tau_{\xi\xi}$, $\tau_{\xi\eta}$ and $\tau_{\eta\xi}$ are Reynolds tension , Mξ and Mη represent the contribution due to sources and external movement of quantity drains (external forces on hydraulic structures, releases and withdrawals of water, tension on the depth, surface tensions, etc.), f is the Coriolis parameter that depends on the geographical latitude and the angular rotation speed of the Earth and ν_V represents the vertical turbulent viscosity.

Transport equation (coordinate σ)

The modeling of matter and heat transport is carried out by the advection-diffusion equation in the three spatial directions. The transport equation in conservative form and in orthogonal curvilinear coordinates in the horizontal direction and σ coordinates in the vertical direction is as follows:

$$\frac{\partial(d+\zeta)c}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\left\{\frac{\partial\left[\sqrt{G_{\eta\eta}}(d+\zeta)uc\right]}{\partial \xi}+\frac{\partial\left[\sqrt{G_{\xi\xi}}(d+\zeta)vc\right]}{\partial \eta}\right\}+\frac{\partial \omega c}{\partial \sigma}=$$
$$\frac{d+\zeta}{\&\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\left\{\frac{\partial}{\partial \xi}\left(D_H\frac{\sqrt{G_{\eta\eta}}}{\sqrt{G_{\xi\xi}}}\frac{\partial c}{\partial \xi}\right)+\frac{\partial}{\partial \eta}\left(D_H\frac{\sqrt{G_{\xi\xi}}}{\sqrt{G_{\eta\eta}}}\frac{\partial c}{\partial \eta}\right)\right\}+\frac{1}{d+\zeta}\frac{\partial}{\partial \sigma}\left(D_V\frac{\partial c}{\partial \sigma}\right)-\lambda_d(d+\zeta)c+S$$

Where D_H and D_V are the horizontal and vertical turbulent diffusion coefficients, respectively. λ_d represents the process of decay of first order and S the terms of source and drain per unit area due to discharge q_{in} or to withdrawal q_{out} of water, and / or heat exchange through the free surface.

State equation

The equation of state used by the Delft3D model is the one proposed by UNESCO. The validity range of this formulation is determined in the ranges 0 < t < 40 ºC, 0.5 < s < 43 ppt:

$$\rho = \rho_0 + A \cdot s + B \cdot s^{3/2} + C \cdot s^2$$

Where,

$$\rho_0 = 999.842594 + 6.793952 \cdot 10^{-2} t - 9.095290 \cdot 10^{-3} t^2 + 1.001685 \cdot 10^{-4} t^3$$
$$-1.120083 \cdot 10^{-6} t^4 + 6.536332 \cdot 10^{-9} t^5$$

$$A = 8.24493 \cdot 10^{-1} - 4.0899 \cdot 10^{-3} t + 7.6438 \cdot 10^{-5} t^2 - 8.2467 \cdot 10^{-7} t^3 - 5.3875 \cdot 10^{-9} t^4$$

$$B = -5.72466 \cdot 10^{-3} + 1.0227 \cdot 10^{-4} t - 1.6546 \cdot 10^{-6} t^2$$

$$C = 4.8314 \cdot 10^{-4}$$

Where, ρ is the density of seawater, t is the temperature of the water and s is the salinity.

Coordinate system

In the horizontal direction the model uses curvilinear orthogonal coordinates. Two coordinate systems are valid: (a) Cartesian coordinates (ξ,η); (b) Spherical coordinates (λ,φ).

In vertical, two different systems can be used: the coordinate system σ (σ-model) and the Cartesian coordinate system Z (Z-model). The above equations are expressed in sigma coordinates, which is the system chosen to carry out this study.

The mesh σ, introduced by Phillips for atmospheric models, consists of layers contained by two sigma levels, which follow the topography of the bottom and the free surface. In this way, the number of vertical layers in the calculation domain will be constant, regardless of the local depth of the water (see Figure No. 5.158).

The coordinate system σ is defined as:

$$\sigma = \frac{z-\zeta}{d+\zeta} = \frac{z-\zeta}{H}$$

Where:

z	vertical coordinate in physical space
ζ	elevation of the free surface on the reference level (in z = 0)
d	depth below the reference level
H	total depth, given by: $H = d + \zeta$

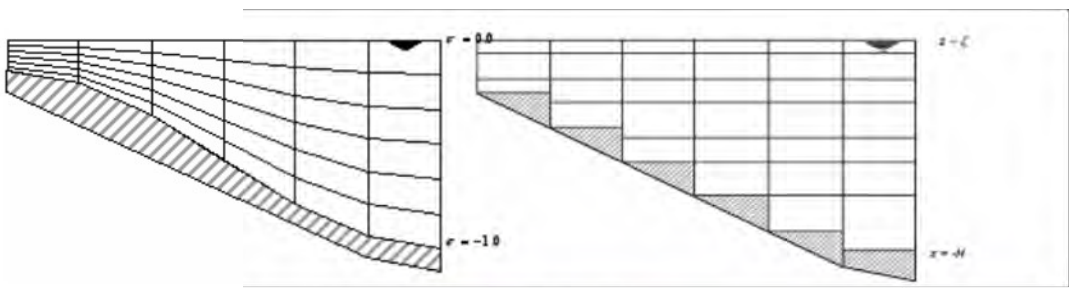


Figure. No. 5.139 Example of mesh σ (left) and mesh Z (right).
Source: Delft3D-FLOW_User_Manual "(http://oss.deltares.nl/web/delft3d/manuals).

Distribution case and meshes

To characterize the field of currents of the study area, the case of waves was selected that is exceeded twelve hours per year, for the predominant direction in deep waters and thus estimate the behavior of the currents in the sector of study. Below are the propagation meshes used to estimate wave currents

. Table No. 5.53 Mesh data used in the flow module of the DELFT 3D model.

Name	Origin X, Origin Y	Angle	Size cells (m)	[Nodes]
M1	696000,1366700	0	25 x 25	Variable

Source: Prepared by Aqua & Terra Consultores Asociados S.A.S., 2015.

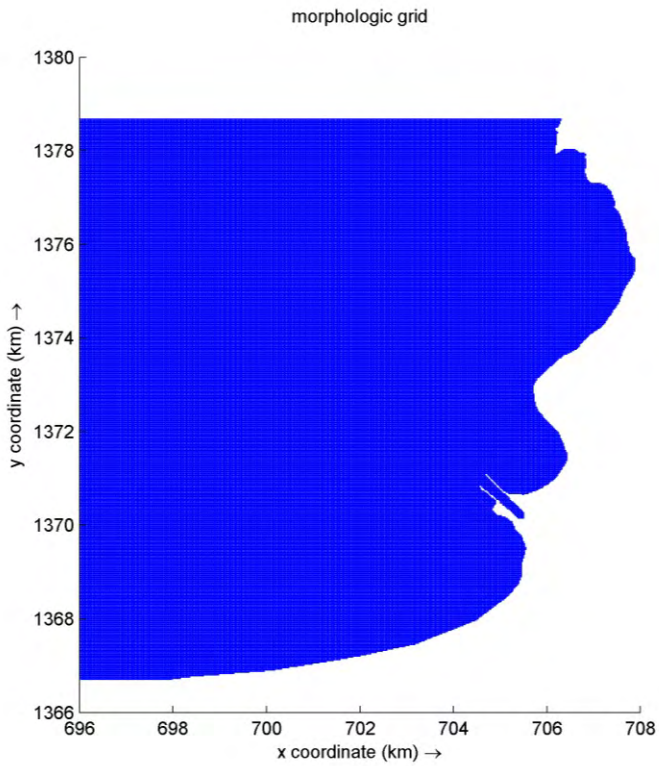


Figure No. 5.140 Meshes for the distribution of currents. F1, mesh on bathymetry with the current condition for extreme waves.

Source: Prepared by Aqua & Terra Consultores Asociados S.A.S., 2015.

The case that was chosen to estimate breaking currents is the case of local waves, for the predominant direction (Case # 4). Below is the selected case and the mesh associated with it.

Table No. 5.48 Case selected to estimate the currents due to breakage of the waves.

Case	Mesh	Magnitude of the Wind (m/s)	Direction	Condition
4	F1	11.0	N	Without Projects
4a	F1	11.0	N	With Projects

Source: Prepared by Aqua & Terra Consultores Asociados S.A.S., 2015.

The case executed to estimate currents due to breakage of the waves corresponds to the conditions that most occur in the study area. The breakage currents in the project area are analyzed below.

- **Study Area**

The following figure shows the results of wave modeling for wave breakage, for the case # 4, which has a wind magnitude of 11.0m / s and an N direction, for the condition without projects (Map MOD_LA_PTO_ANT_25).

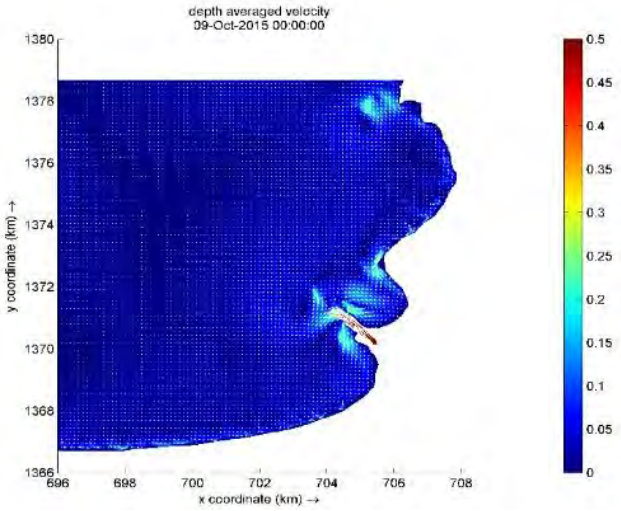


Figure No. 5.141 Currents due to breakage of the waves. Case # 4 Wind magnitude = 11.0m / s, Direction = N - Initial condition, no projects, detail mesh. Local surf.
Source: Produced by Aqua & Terra Consultores Asociados S.A.S., 2015.

In the previous figure you can see the currents that are produced by breakage of the waves and the effect of the Leon River on them. In terms of the magnitude of the currents, as can be observe, those that come from the León river are much more significant than those produced by the breaking of waves in the area. Towards the north of the mouth of the León River, a current can be observed that comes out of it and that has a south-north direction, which meets a north-south current, which generates a return current in the central sector of the bay that forms in this sector.

The magnitude of the currents due to breakage of the waves is of the order of 0.2 m / s, which is a very low magnitude when compared with those obtained at the mouth of the river León.

The following figure shows the results of the wave modeling of currents, for the case # 4a, which has a wind magnitude of 11.0m / s and an N address, for the condition with works (Map MOD_LA_PTO_ANT_26).

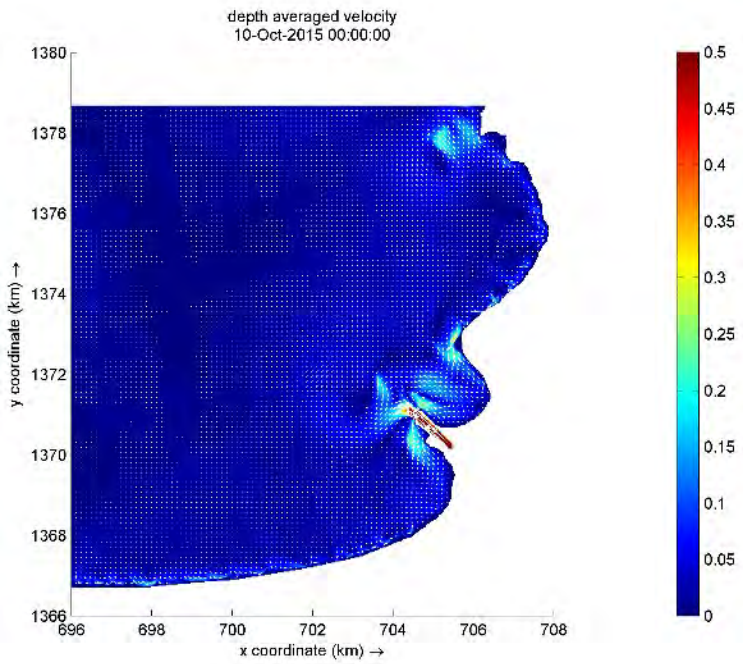


Figure No. 5.142 Currents due to breakage of the waves. Case # 4 Wind magnitude = 11.0m / s, Direction = N - Final condition, with projects, detail mesh. Local surf.
Source: Produced by Aqua & Terra Consultores Asociados S.A.S., 2015.

For the final condition (with projects), you can see the same pattern of breakage currents, because the depth to which are the dredging and dumping of the material from it, the waves are not yet very influenced by the refraction and diffraction of the waves.

From the modeling of the currents by rupture it can be observed that the proposed dredging and dumping projects for the development of Puerto Bahía Colombia de Urabá do not affect the littoral dynamic of the study area.

ϖ Analysis of the littoral dynamics of the Landfill area

To analyze the influence of the dumping of dredged material, in the landfill area, on the littoral dynamics of the area surrounding it, an analysis has been made on how

the conditions of the depth and more specifically, the depths or peak of maximum coronation of the landfill can influence the modification of the incident wave patterns from the modification of the wavelength L, which depends directly on the T wave period.

In this way we proceeded to estimate wavelength of the waves for current conditions and future conditions, estimating, what variations there are in terms of wavelength due to the effect of the dredged material release and the changes it produces on the final level of the bottom.

The procedure to carry out this influence was calculated the peak period of the study area for the most critical case of waves (case # 4 Wind magnitude = 11.0m / s, Direction = N), from figure Hs Vs Tp. From the figure that compares wave heights with peak periods, we have that for a height of 0.9 m in height there are periods that vary between 3 s and 8 s, with the lower values being the corresponding ones for waves generated locally and the values high for waves generated in deep waters.

Wavelength of the swell for the Landfill sector

The following figure shows the location and geometric configuration of the proposed landfill, for the dumping of dredged material, from the projects of Puerto

Bahía Colombia de Urabá.

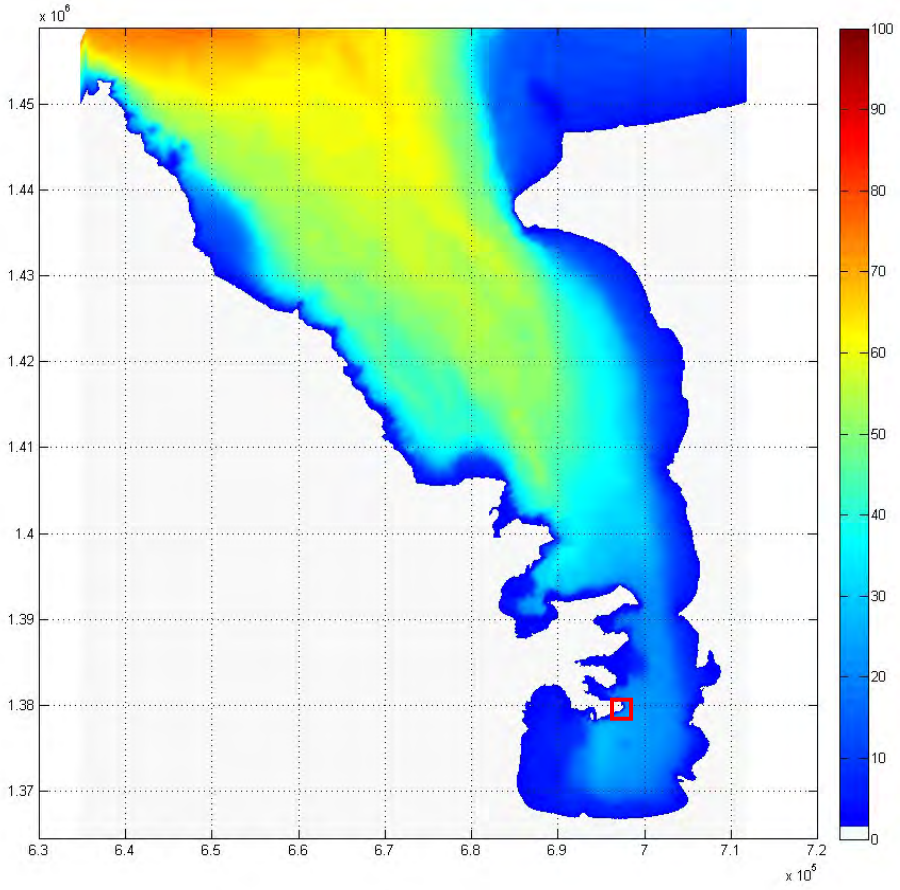


Figure No. 5.143 Location and geometric configuration of the landfill area.
Source: Aqua & Terra Consultores Asociados S.A.S, 2013

From the previous figure we can obtain the dimensions of the landfill, which are shown in the following table

Table No. 5.49 Data of the área of the landfill

	X (m)	Y (m)	Total Area (m2)
Landfill	2000	2000	4000000

Source: Aqua & Terra Consultores Asociados S.A.S., 2013.

- **Wavelength for the initial condition of the Landfill**

The average depth of the landfill was estimated at 24 m.

The wavelength was estimated from the following expression:

Si h/Lo > 0.5 so:

L=Lo=g*T^2/(2*π)

Si h/Lo<=0.5

$$L = Lo * Tanh\left(\frac{2 * \pi * ho}{L}\right)$$

Where:

Lo=g*T^2/(2*π)

T= peak period (s)

g= gravity (m/s^2)

ho=Depth (m)

L= Wavelength (m)

For the calculation of the initial wavelength, a period of 5 seconds was chosen, taking into account that, as will be seen below, the wave measurement campaign on which this study was based, shows that the periods move in around 4 and 5 seconds, but it is the latter that has the greatest potential for sediment transport.

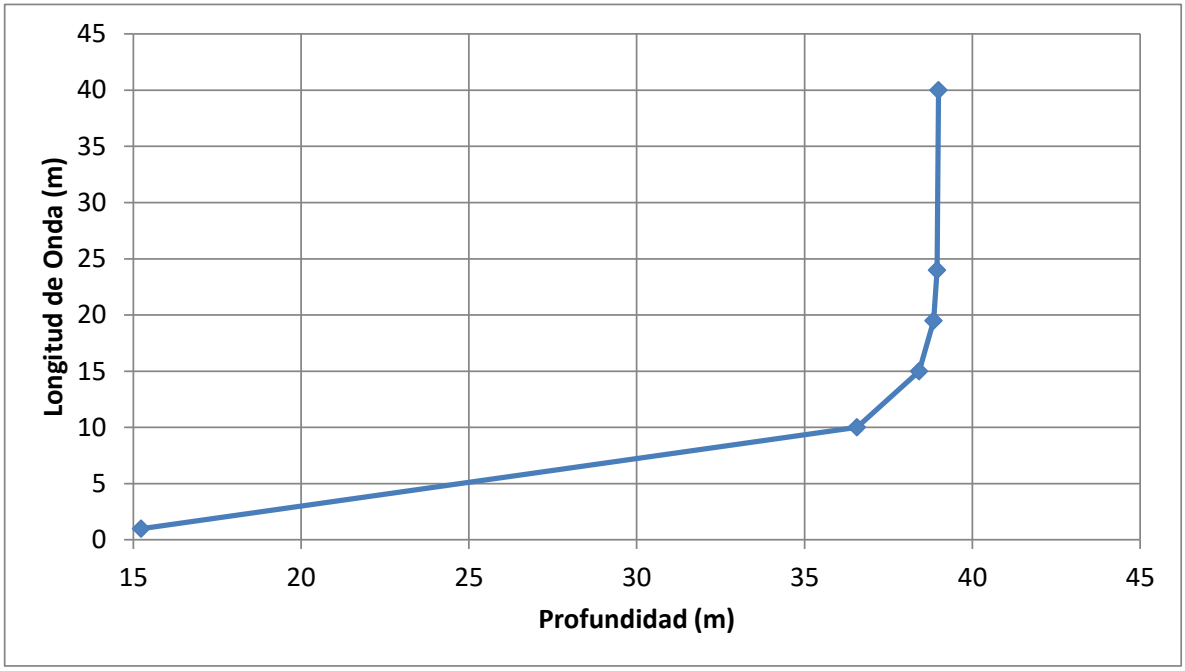


Figure No. 5.144 Wavelength for different depths, for the initial condition of the landfill.
Source: Aqua & Terra Consultores Asociados S.A.S, 2013

From the previous figure we can see that the wavelength for a period of 5 sec is not altered after the 19.5 m depth. For this reason, the surf will not be affected by the bottom if it does not decrease beyond that depth.

It is important to note that this area is known as indefinite depths, that is, in this area the waves do not feel the bottom as they spread, and therefore do not affect it. It is defined as h = L / 2, that is to say, that from a depth greater than half a wavelength, the waves are not affected by the seabed.

- **Wavelength for the final condition of the Landfill**

To estimate the height of coronation of the landfill, after pouring the material from the dredging of the project of Puerto Bahía Colombia de Urabá, the total dredged volume was started (see Table No. 5.56) and the geometric configuration of the landfill (see Table No. 5.57).

Table No. 5.50 Total volume of dredged material

	Puerto Bahía Colombia de Urabá (m3)	Total Volume (m3)
Dredging Volume	2800000	2800000

Source: Aqua & Terra Consultores Asociados S.A.S., 2015.

Table No. 5.51 Geometric configuration of the landfill

	X (m)	Y (m)	Área Total (m2)
Landfill área	2000	2000	4000000

Source: Aqua & Terra Consultores Asociados S.A.S., 2015.

Taking into account the large extent of the landfill and the small volume that constitutes dredging, it is that this would not reach more than a meter and a half high the filling.

As a starting point, the minimum depth in the landfill in current conditions is 23 m. If one considers that its depth was raised by 1.5 m, the minimum final depth would be 21.5. this depth is less than 19.5 (2 m difference), and therefore it can be determined that the waves will not change and their dynamics in the area of interest.

It is important to note that waves are the main agent responsible for coastal dynamics, so it can be said that if this is not affected by the seabed, its distribution through the area of interest will not be affected by the implementation of the project, and consequently, the coastal dynamics either.

This had already been confirmed with wave modeling and currents mentioned in previous numerals.

❖ CONCLUSIONS

Broadly speaking, it can be noted that for the same case of distribution the variations of wave patterns, in the three alternatives modeled in this study, are practically imperceptible.

So that the beaches near the landfill suffer an affectation, or a tilt that generate backward movement in some areas and accretion in others, it would have to generate a really marked diffraction pole within the bathymetric configuration of the area, generating and modifying the patterns of the wave that spreads, by a sensible decrease in the depths in relation to the characteristic periods of the predominant

swell and it was demonstrated that this does not happen with the dumping of material in the proposed landfill.

After analyzing all the wave propagation figures, it can be concluded that the differences enter the initial condition, which represents the current and future state of the zone, in which the dumping of material is already taken into account, it is maximum 1 cm in wave height in the area immediately after release; In the other sectors of the study area, no variation can be observed, because the impact of the discharge on the coastal dynamics is local.

With this magnitude, it can be said that the future condition does not significantly modify the height of the waves that currently occur in the study area and, therefore, the littoral dynamic is not affected. Therefore, no substantial changes are expected in the coasts near the Project

Regarding the direction of the swell in the study area, it can be noted that the variation is almost zero, because the discharge that Puerto Bahía Colombia de Urabá intends to carry out in the study area does not significantly modify the bathymetry of the sector. This dumping does not produce a hard point that generates wave diffraction, nor a significant change at depth level in relation to the periods that occur in the area, as was analyzed in previous chapters, so the seabed does not generate processes of refraction that modify the direction of the waves. It is important to consider that the waves in nature also have a degree of angular dispersion that can be similar to the magnitudes obtained here, therefore it cannot be considered that these changes represent a great influence on the current dynamics.

It is important to note that this area is known as indefinite depths, that is, in this area the waves do not feel the seabed as they spread, and therefore do not affect it. It is defined as h = L / 2, that is to say, that from a depth greater than half a wavelength, the waves are not affected by the depth. For this reason, only from more or less 19.5 m depth, is that it can be affected for waves of 5 seconds peak period.

As a conclusion of this study, it can be confirmed that the project of Puerto Bahía Colombia de Urabá do not have any influence on the littoral dynamics and this can be observed by the fact that wave patterns have not undergone significant changes in the study area.

- *Tides*

The astronomical tide is defined as the set of regular movements of sea level rise and fall with periods close to 12 or 24 hours that are produced by the gravitational effects of the earth-moon-sun system. From the practical point of view, it is necessary to know the behavior of tidal waves, especially to predict the amplitude of the same at a certain time and place. That is why a way to approach the study of their behavior is to consider the astronomical tide as the sum of a finite number of waves, whose amplitude and data are known because they have been associated with some planetary movement.

According to the previous hypothesis, several researchers have worked on the development of periodic components of the driving force as forcing generated from the tide. Darwin and Doodson managed to carry out this breakdown by performing an astronomical analysis taking into account the movements of the earth, moon and sun, from which they determined the frequency and relative importance of each of the components.

The breakdown is basically done assuming that the generating forces produced by the moon and the sun in their variable trajectories are generated by a limited number of fictitious planets. Each of these planets revolves around the earth with a circular orbit located in the level of the equator at a constant angular velocity, and they are selected in such a way that, one or a combination of several of them, reproduce the frequency of a certain disturbance astronomical

- Calculation methodology

The description and prediction of the tide in a given location could be done through what is called harmonic tidal analysis, which consists of decomposing the records of sea level in a finite number of waves whose period and phase have been perfectly established, since they coincide with the periods of some of the relative astronomical movements between Earth, Moon and Sun, as has been described above. In general terms, the method of harmonic analysis consists of measuring the sea level during a certain period of time and obtaining, from said record, the amplitudes and phases of the component waves. These parameters are called harmonic components, due to the implicit assumption that the responses of seas and oceans to tidal forces do not change over time. In this case, the method that is going to be presented is the one elaborated by Dronkers (1964) and based on the least squares.

The astronomical tide approaches, then to the sum of those constituent waves in the following way:

$$S_{MA}(t) = a_0 + \sum_{i=1}^{n} a_i + \cos(\overline{w}_i t + \varphi_i)$$

Where:

a_0 is the amplitude of the average reference level

a_i is the amplitude of the wave i

ωi is the frequency of the component wave i

φi is the phase shift of the component wave i

t is the moment when the tide is calculated

n is the number of components considered

Next, harmonic components will be obtained to predict tidal events in a period that is between January 1, 1990 and January 1, 2000. The harmonic components were obtained from the TPXO model, which is one of the global models of tide, which provides four semidiurnal harmonic components (M2, S2, N2, K2), four diurnal components (K1, O1, P1, Q1), two long period (Mf and Mm) and three short period components (M4) , Mn4, Ms4) in a mesh with global coverage of 1440 x 721 points with 0.25º of spatial resolution. In this study we have used the most recent database, TPXO7.2. Figure No. 5.164 shows the location of the TPXO point closest to the study area.

Table No. 5.52 Tidal harmonic components, obtained from TPXO

Component	Frequency	Period (hr)	Amplitude (m)	Phase (°)
m2	28.984101	12.42	0.0693	151.22
s2	30	12	0.0168	12.35
n2	28.43973	12.66	0.0255	120.74
k2	30.082137	11.97	0.0052	0.04
k1	15.041069	23.94	0.0937	239.45
o1	13.943036	25.8	0.0576	240.29
p1	14.958931	24.07	0.029	244.4
q1	13.398661	26.87	0.0082	236.03

Component	Frequency	Period (hr)	Amplitude (m)	Phase (°)
mf	1.098033	328	0.0168	356.53
mm	0.544375	661	0.0081	353.33
m4	57.96821	6.2103	0.0019	151.72
ms4	58.984104	6.1033	0.005	340.28
mn4	57.423	6.2393	0.0018	193.14

Source: Aqua&Terra Consultores Asociados S.A.S, 2014

Figure No. 5.145 Location of the point where the harmonic components of TPXO were obtained.

Source: Aqua &Terra Consultores Asociados S.A.S, 2014.

With the components obtained from the TPXO and the equation that relates the amplitude and the phase of these, the astronomical tide series was constructed for the point in the outskirts of the gulf. The complete series is shown in the following figure:

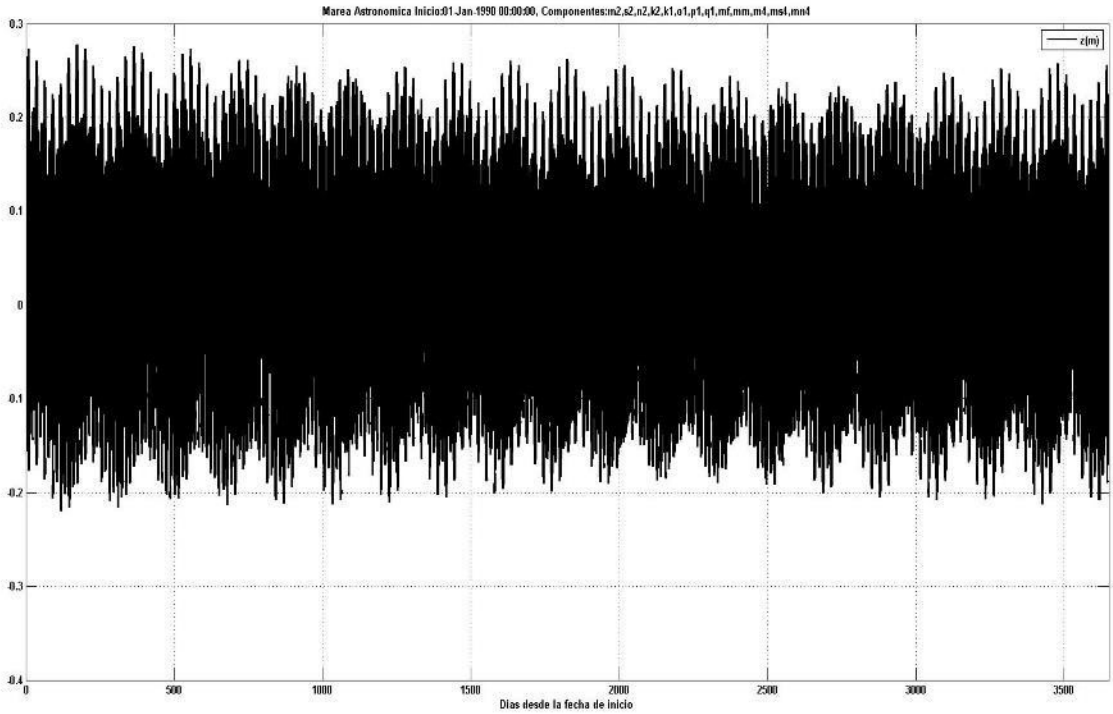


Figure No. 5.146 Series of astronomical tide for the point closest to the study area.
Source: Aqua &Terra Consultores Asociados S.A.S, 2014.

- Average sea level regimen

The tidal level regime is constructed from the sea level data series at the point shown in Figure No. 5.164. Although this site is not located within the study area, the spatial variation of long waves in the Gulf of Urabá is not significant.

Based on this information and the previously accepted hypothesis, we have the sea level series, with which the average sea level regime can be built. For this, the sea level series is ordered from lowest to highest and assigning to each data a probability P = i / (n + 1), where P is the probability of non-exceedance, i the number of order of the data, and n the total number of data analyzed. The results obtained are presented in Figure No. 5.166.

As can be seen, sea level is not a relevant variable in the study area. The maximum values, with respect to half the sea level, do not exceed 0.3 m in height.

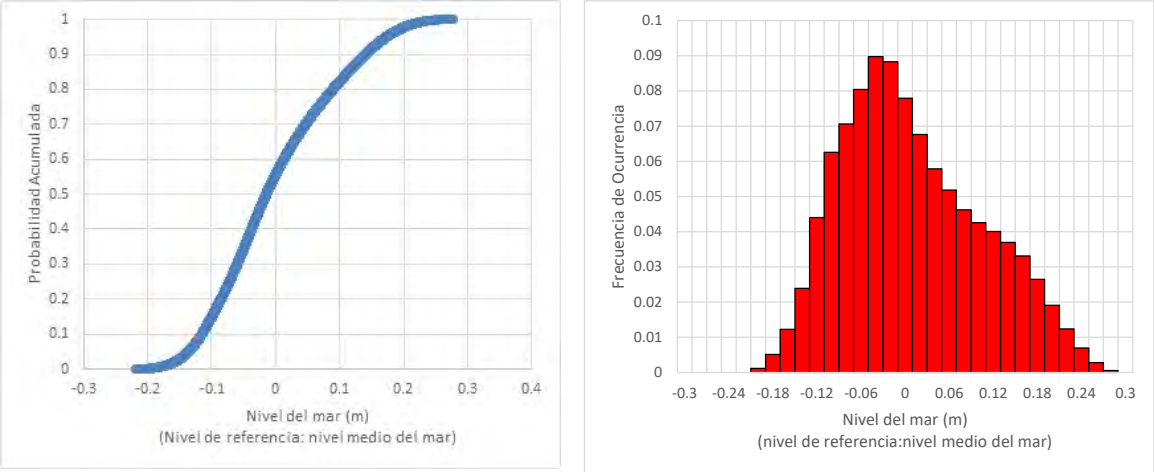


Figure No. 5.147 Average level of sea level at the point closest to the study area, a) Distribution function and b) density function.
Source: Aqua & Terra Consultores Asociados S.A.S, 2014.

- *Tropical Storms*

The Caribbean Sea region is characterized by the formation of tropical cyclones. Traditionally, hurricanes develop over warm waters between June and November, due to the action of the trade winds converging on the West Coast of Africa (Mo et

al., 2001), however Shapiro and Goldenberg (1998) and Goldenberg et al. to the. (2001) analyzed the relationship between sea surface temperature (SST) and the formation of cyclones in the Atlantic, demonstrating that there is no correlation between temperature and cyclone formation. Tropical cyclones are classified according to the Saffir-Simpson scale according to the speed of the winds (see Table No. 5.88).

Table No. 5.53 Classification of Tropical Cyclones according to the Saffir-Simpson scale

CLASIFICATION	WIND SPEED (km/h)
Tropical Depression(TD)	<63
Tropical Storm(TS)	63 – 117
H1	119 – 153
H2	154 – 177
H3	178 – 209
H4	210 – 249
H5	>250

Source: National Hurricane Center, s.d.

The formation of tropical cyclones is deeply studied in the National Hurricane Center (United States of America) due to its economic and social importance. With the exception of the San Andres and Providencia Islands region, the Colombian Caribbean has been considered as an area of low probability and development of tropical storms, according to the National Oceanographic and Atmospheric Administration (NOAA). tropical storm or hurricane touch the north coast of South America (Gerrish, 1988).

Ortiz (2012) conducted an analysis of the hurricanes that have touched the Colombian coast between 1900 and 2010, concluding that a total of 10 storms have affected the Caribbean coast of Colombia in this period. In the continental area six storms have been recorded (5 tropical storms and one category 1 hurricane) and seven events (2 tropical depressions, 3 tropical storms, one category 1 hurricane and one category 3 hurricane) affected the insular area (see Figure No. 5.167).

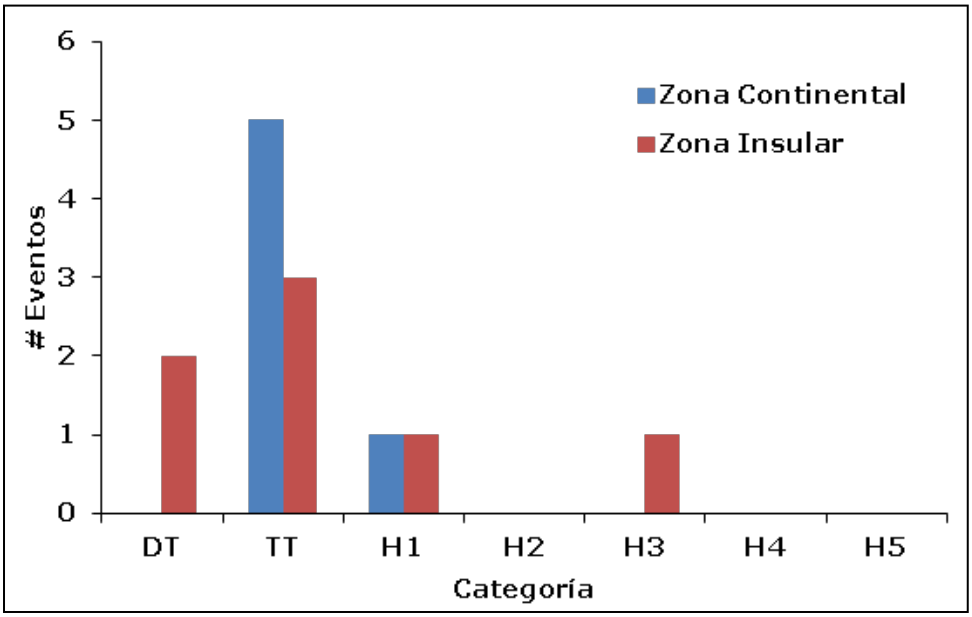


Figure No. 5.148 Significant events that have affected the Colombian Caribbean (Insular and Continental) between 1900 - 2010
Source: Tomado de Ortiz, 2012.

Up next is the trajectory and a brief description of the main events that have passed through the Colombian Caribbean coast. The main events that have been recorded have been, a storm without a name that happened in June 1933, Irene 1971, Joan 1988 and Bret 1993 and Cesar in 1996 (Ortiz, 2007)

Irene 1971: formed on the west coast of Africa reaching quickly to the Caribbean, where it loses intensity to meet the Windward Islands where it loses strength, after passing through the North Coast of Colombia gains strength to reach the category of hurricane (1) off the coast of Nicaragua

(Simpson and Hope, 1971) (see Figure No. 5.168).

Figure No. 5.149 Hurricane Irene's trajectory (1971)
Source: Weather Underground, 2012.

Hurricane Joan (1988): reached hurricane conditions on the west coast of the La Guajira Peninsula at 30 nm (nautical miles) off the coast of Colombia, although passing through the Colombian coast was a tropical storm, the rain that accompanied the storm caused severe damage caused by the floods, leaving a total of 25 dead and approximately 27,000 displaced persons passing through the country (Gerrish, 1988) (see Figure No. 5.169).

Figure No. 5.150 Trajectory of Hurricane Joan (1988)
Source: Weather Underground, 2012.

Hurricane Bret (1993): touched land on the Venezuelan coast and continued its path to Colombia, where it meets the high elevations of the Sierra Nevada de Santa Marta, causing a considerable weakening, however, after crossing this area it gains strength again until reaching its maximum speeds off the Nicaraguan coast. On its way through Colombia, it left a dead person and a wounded person (Pasch, 1993) (see Figure No. 5.170).

Figure No. 5.151 The trajectory of Hurricane Bret (1993)
Source: Weather Underground, 2012.

Hurricane Cesar (1996): formed from a tropical wave that crossed Dakar, Africa moving to the west, until it develops in the region of the Windward Islands. Cesar continued its path towards the West increasing its intensity, losing its intensity when approaching the coast of South America, and later it reaches category of hurricane in the coast of Nicaragua, when crossing Nicaragua it arrives at the Pacific Ocean where it intensifies again and changes his name to Douglas (Avila, 1996) (see Figure No. 5.171).

Figure No. 5.152 Trajectory of Hurricane Cesar (1996)
Source: Weather Underground, 2012.

From the information presented above it is possible to conclude that the region of the Gulf of Urabá has not been historically affected by tropical storms, which does not present a risk for the execution and operation of the project.

- *Marine water quality*

The project has some works in the marine part such as the viaduct and the terminal in water and the dredging activities of deepening and the disposal of dredged material in the landfill, therefore, the A3 stations were located on the A9 in Bahía Colombia to determine the quality of seawater as a baseline. It is worth mentioning that station A9 was located in a nearby area as a control point with respect to the intervention projects of the project in Bahía Colombia.

Sampling stations for water quality and marine sediments

Table No. 5.14 shows the Magna Sirgas flat coordinates originating from Bogotá of the sampling stations defined for the analysis of the water quality and marine sediments in the Project study area and in Figure No. 5.172 the location is presented. of said stations.

Table No. 5.54 Location of water quality and marine sediment sampling stations

Id	Station name	Flat coordinates Magna Sirgas origin Bogotá	
		East	North
A3	Viaduct Station	703,792.94	1,371,083.51
A4	Maneuvering Area Station 1	702,783.75	1,370,390.87
A5	Maneuvering Area Station 2	702,487.86	1,371,110.59
A6	Maneuvering Area Station 3	702,943.68	1,371,628.00
A7	Access Channel Station Phase I	702,099.85	1,371,870.99
A8	Control point station	696,387.84	1,372,825.31
A9	Landfill	697,792.41	1,375,464.03

Source: Produced by Aqua & Terra Consultores Asociados S.A.S, 2015

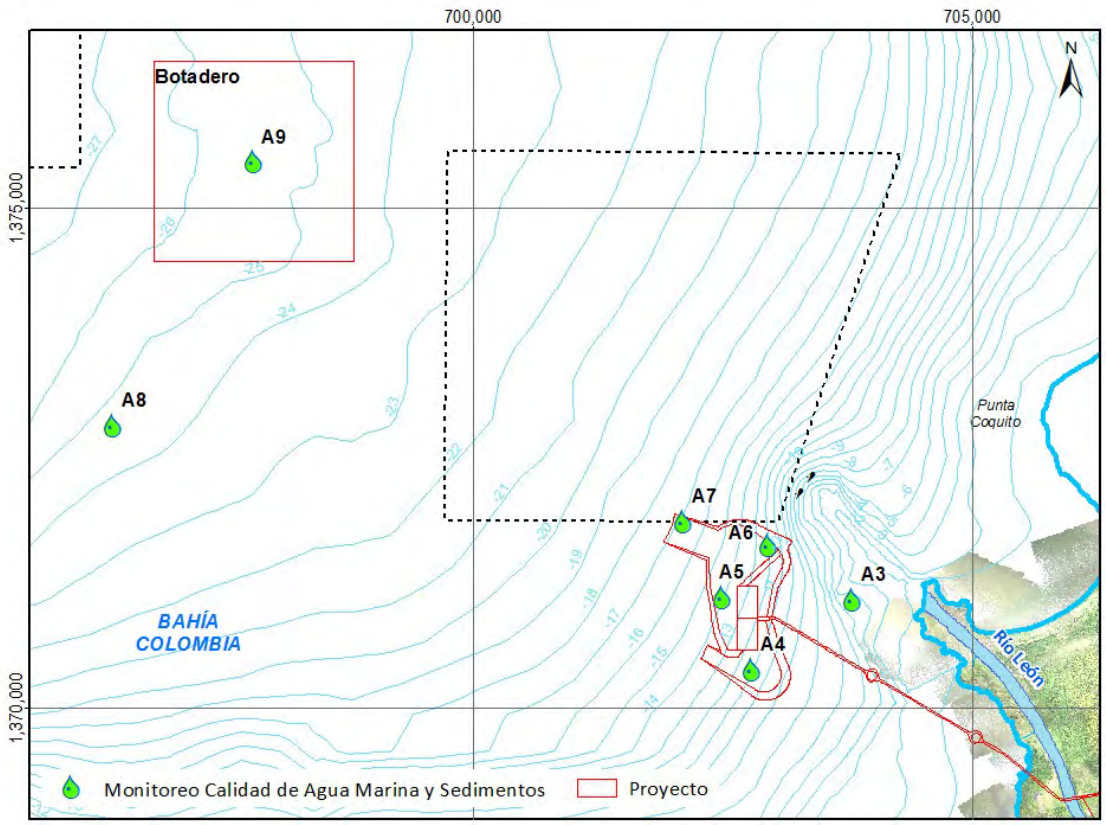


Figure No. 5.153 Location of water quality and marine sediment sampling stations
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

- Results obtained from seawater quality

The physicochemical and bacteriological parameters evaluated for the characterization of seawater that may be affected by the development of the project correspond to those established in the terms of reference for the preparation of the Environmental Impact Study - EIA in construction or expansion and operation projects. Maritime ports of great draft (MM-INA-05

Below are the results of the parameters that were recorded In Situ and those evaluated in the laboratory.

❖ Results of the parameters in situ

Table No. 5.61 shows the results of the parameters that were recorded in situ for the stations located in Bahía Colombia.

Table No. 5.55 Results of measurement of parameters in situ – Agua Marina

Sampling point	pH (units)	Temperature (°C)	Dissolved Oxygen (mg / L)	Conductivity, ms / cm	% oxygen saturation
A3	6,69	29,1	6,67	6,60	86,75
A4	7,08	29,8	7,64	9,28	100,58
A5	6,84	29,4	7,54	9,17	98,58
A6	7,79	28,5	7,02	23,3	90,35
A7	7,58	28,6	7,52	16,8	96,95
A8	7,56	28,7	7,50	26,7	96,87
A9	8,1	29,2	7,88	28,0	97,46

Source: SGS Colombia S.A.S (Julio 2015)

❖ Results analyzed in the laboratory

Table No. 5.62 presents the results of the parameters that were analyzed in the laboratory for the stations located in Bahía Colombia.

Table No. 5.56 Parameters analyzed in the laboratory – Agua Marina

Parameters	Results of the sampling stations						
	A3	A4	A5	A6	A7	A8	A9
Acidity, mg CaCO3 / L	6,6	6,0	7,6	6,6	6,8	5,6	10
Total Alkalinity, mg CaCO3 / L	56	58	66	64	69	73	113
True Color, UPC	22	19	15	16	16	13	18
Biochemical Oxygen Demand, mg O2 / L	10	<2	<2	<2	10	4,5	<2
Chemical Oxygen Demand, mg O2 / L	24	<10	<10	<10	23	11	<10
Detergents, mg SAAM / L	<0,04	<0,04	<0,04	<0,04	<0,04	<0,04	<0,04
Calcium hardness, mg CaCO3 / L	748	1190	1380	2030	1780	1940	3470
Total Hardness, mg CaCO3 / L	977	1760	1700	3970	2130	3820	4130
Total phenols, mg Phenol / L	<0,075	<0,075	<0,075	<0,075	<0,075	<0,075	<0,075
Total phosphorus, mg P / L	0,2	0,040	0,040	0,070	0,070	0,030	0,030
Fats and Oils, mg GyA / L	<0,8	<0,8	<0,8	<0,8	<0,8	<0,8	<0,8
Total Nitrogen, mg N / L	<5,16	<5,16	<5,16	<5,16	<5,16	<5,16	<5,16
Total Dissolved Solids, mg SDT / L	7390	8690	16800	14500	17300	21000	7630
Sedimentable solids, ml / L	0,1	0,1	0,1	0,1	0,1	0,10	44
Total Suspended Solids, mg SST / L	85	11	5,1	13	22	30	13
Turbiedad, NTU	42,3	2,16	2,01	3,52	7,61	5,19	4,85
Total coliforms, NMP / 100 ml	2489	1119,9	>MNPC*	>MNPC**	307600	>MNPC**	41060000
Coliforms (E.coli), NMP / 100 ml	206	1,0	19	403400	2000	111800	4730000
Polynuclear Aromatic Hydrocarbons, mg Compound / L	<0,000053	<0,000053	<0,000053	<0,000053	<0,000053	<0,000053	<0,000053

Parameters	Results of the sampling stations						
	A3	A4	A5	A6	A7	A8	A9
Total bar, mg Metal / L	<0,0855	<0,0855	<0,0855	<0,0855	<0,0855	<0,0855	<0,0855
Total Cadmium, mg Metal / L	<0,002	<0,002	<0,002	<0,002	<0,002	<0,002	<0,002
Total Copper, mg Metal / L	0,11	0,0049	0,0049	0,0049	0,005	0,0049	0,0049
Total Chromium, mg Metal / L	0,003	0,0026	0,0026	0,0026	0,0026	0,0026	0,0026
Mercury Total, mg Metal / L	0,00027	0,001	0,00027	0,001	0,00027	0,00027	0,00027
Total Nickel, mg Metal / L	0,014	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022
Total Silver, mg Metal / L	<0,0004	<0,0004	<0,0004	<0,0004	<0,0004	<0,0004	<0,0004
Total Lead, mg Metal / L	<0,004	<0,004	<0,004	<0,004	<0,004	<0,004	<0,004
Selenium Total, mg Metal / L	0,142	0,209	0,209	0,346	0,253	0,367	0,39
Total Arsenic, mg Metal / L	0,010	0,010	0,010	0,023	0,010	0,024	0,010
Total Zinc, mg Metal / L	0,06	0,47	0,08	0,07	0,30	0,16	0,13
Chlorophyll A mg / m3	3,61	2,05	1,71	1,17	3,19	19,1	1,13
Chlorophyll B mg / m3	5,95	3,34	2,79	1,89	5,23	31,2	1,84

* > VNTC: Very numerous to count. the result is > 24196 NMP/100 ml.
** > VNTC: Very Numerous to count. the result is >24196 NMP/100 ml. Dilution 10-3
Source: SGS Colombia S.A.S (July 2015)

- Analysis of seawater results

Next, an analysis of the physicochemical and bacteriological parameters registered in situ and in the laboratory for the stations in Bahía Colombia in the Gulf of Urabá, named A3, A4, A5, A6, A7, A8 and A9, which were in the area of intervention of the project and a control station.

- **Hydrogen potential – pH Units**

Hydrogen potential, considered an important indicator of marine water quality, which registered a mostly neutral trend in five (5) of the seven (7) monitored marine water stations, located in the Bahía Colombia Sector in the Gulf of Urabá; this behavior is associated with the moderate content of both acidic and alkaline compounds in water. The two stations with the highest pH values were A6 and A9. The values in general ranged from 6.69 to 8.29 units with an average of 7.38 Units.

It is important to note that the values of the potentials are in a favorable range for the development of aquatic organisms. Regarding the regulatory regime, it fully complies with the maximum regulatory limits established in Decree 1076 of 2015, Chapter 3, Section 9 Articles 2.2.3.3.9.7, 2.2.3.3.9.8 and 2.2.3.3.9.10 reaffirming that water meets with the admissible quality criteria for the destination of the resource for recreational purposes and for the preservation of vegetation and wildlife to which this parameter refers. This behavior is illustrated in Figure No. 5.173.

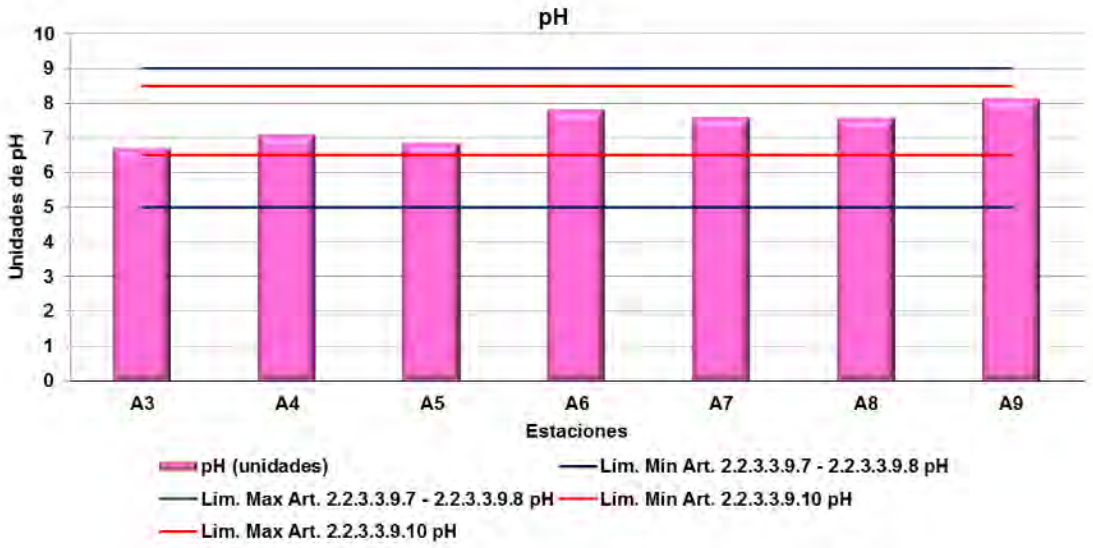


Figure No. 5.154 . Potential behavior of Hydrogen – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results of SGS S.A.S, 2015

❖ Temperature

ϖ Temperature is of great importance because it determines the climatic regions and the distribution of marine species; in turn, it influences the reproduction and periodicity of aquatic life, and the decomposition of organic matter. The average temperature in Bahía Colombia was 29.04 ° C, where the values oscillated between 28.5 ° C and 29.8 ° C; it can be proven that no significant variations were recorded, in Figure No. 5.174 such behavior is observed; however, in station A4 I present the highest temperature.

On the other hand, Decree 1076 of 2015, Chapter 3, Section 9, articles 2.2.3.3.9.7, 2.2.3.3.9.8 and 2.2.3.3.3.10 do not establish an allowable limit for this parameter; notwithstanding the TULAS (Unified Text of the Secondary Environmental Legislation that is the Standard of Environmental Quality and discharge of effluents to the water resource in Ecuador) defines that the maximum permissible limit for marine waters is the local ambient temperature + 3 ° C (32 ° C), establishing that the monitored points registered values lower than the mentioned limit. It is important to highlight that the reported values are in accordance with the ambient temperature of the study area and are suitable for the vital processes of microorganisms.

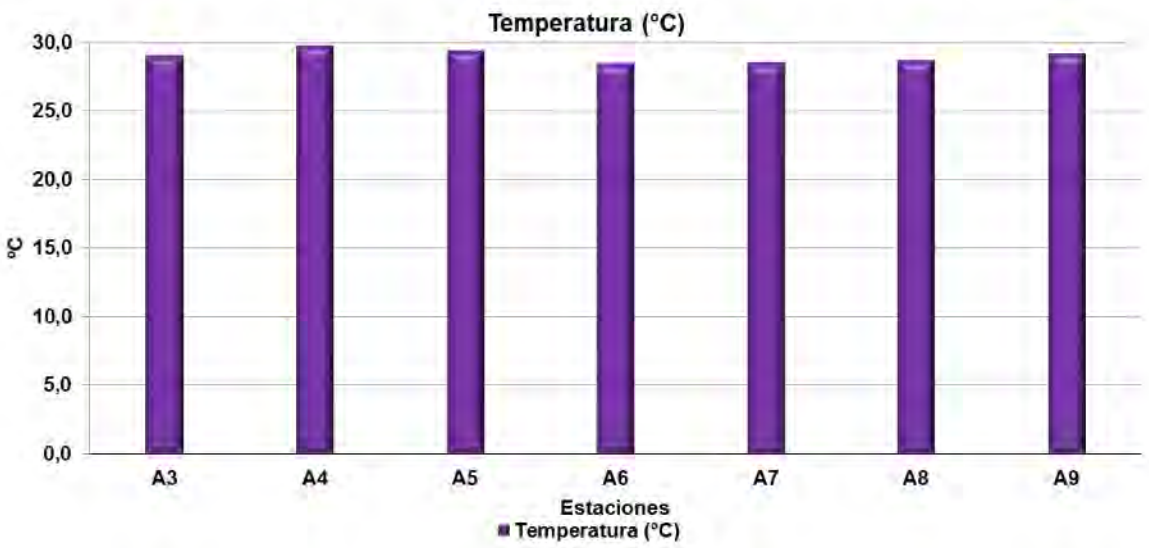


Figure No. 5.155 Temperature Behavior – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Dissolved Oxygen

Oxygen (O2) from the atmosphere dissolves directly in surface waters, or is generated by photosynthesis in the upper illuminated layers. With the increase in depth, dissolved oxygen decreases, partly when consumed by the respiration of microorganisms and on the other hand by the microbial decomposition of organic detritus and by the absorption phenomenon.

According to the results, the dissolved oxygen reported in the stations in Bahía Colombia ranged between 6.67 mg / L and 7.88 mg / L with an average of 7.40 mg / L; station A4 recorded the highest concentration for this parameter, however the variation between this and the other stations is slight. (See Figure No. 5.175).

Regarding the regulatory restrictions for dissolved oxygen, Article 2.2.3.3.9.10 of Decree 1076 of 2015, Chapter 3, Section 9 establishes that the concentration of Dissolved Oxygen in marine and estuarine waters for the destination of resource for preservation use of vegetation and wildlife should be higher than 4 mg / L where it can be established that

COLOMBIA. MINISTRY OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. Decree 1076 (May, 26, 2015). Op Cit.

The stations monitored as a baseline in the Bahía Colombia Sector in the Gulf of Urabá registered full compliance, presenting favorable concentrations for the metabolic activities of the microorganisms and the decomposition processes of the organic matter.

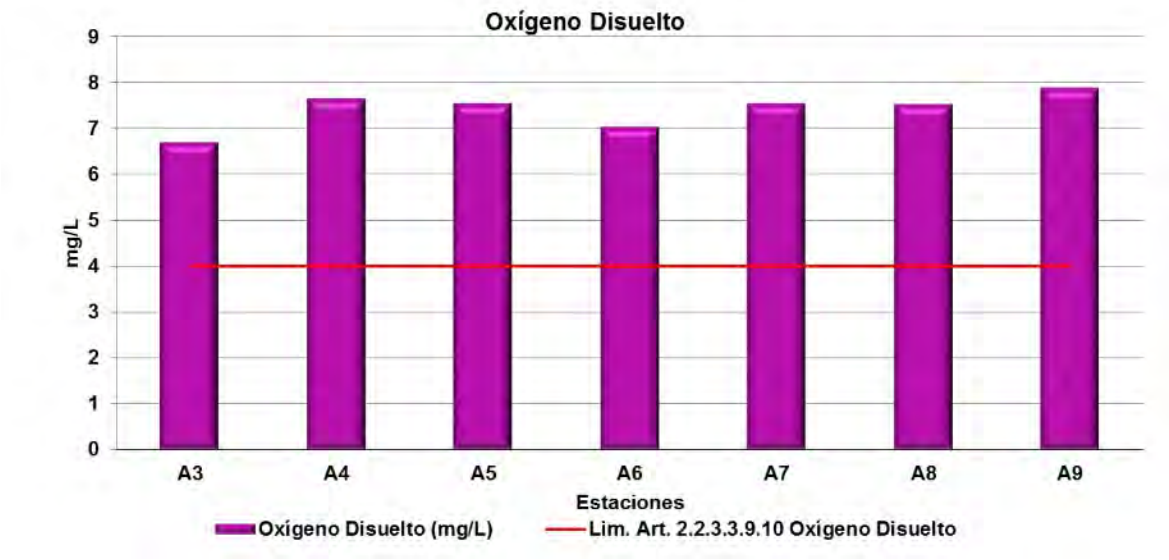


Figure No. 5.156 Dissolved Oxygen Behavior – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

On the other hand, the percentages of oxygen saturation in all the stations registered a range of percentages between 86.75% to 100.58% (see Figure No. 5.176); considering themselves optimal, since the reported values are higher than the minimum acceptable percentage, which is 70%; According to the above, it can be established that the marine ecosystem has favorable conditions for the survival of the species and the biological processes of reproduction. The percentages recorded comply fully with the provisions of Decree 1076 of 2015, Chapter 3, Section 9, articles 2.2.3.3.9.7 (Quality Criteria for recreational purposes through primary contact) and 2.2.3.3.9.8 (Quality Criteria for recreational purposes through secondary contact).

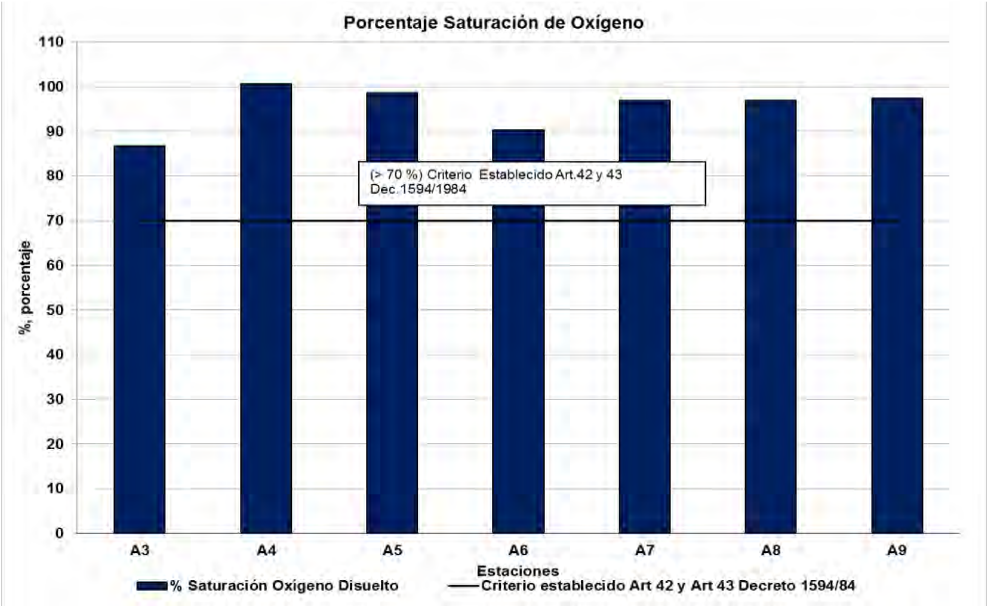


Figure No. 5.157 % Dissolved Oxygen Saturation - Marine Water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Conductivity

The conductivities registered in the Bahía Colombia stations were found in a range between 6.60 mS / cm to 28.0 mS / cm with an average of 17.1 mS / cm, considering these values in accordance with the characteristics of the water, graphically is presented in Figure No. 5.177. According to (Rodier 2009) it presents a high degree of mineralization when registering conductivities higher than 10 mS / cm; these values are associated with the content of ions such as chlorides, sulfates, Ca, Mg, Na, P, bicarbonates present in water.

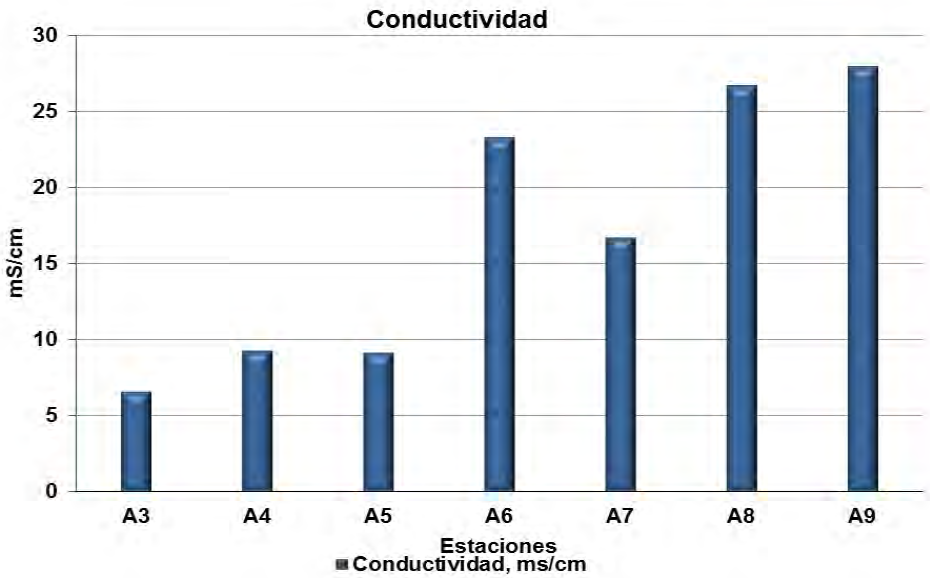


Figure No. 5.158 Behavior Conductivity – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Acidity and Alkalinity

The analysis of Total Acidity and Total Alkalinity allows to determine if the water has a considerably higher capacity to neutralize acids. According to the results reported for Bahía Colombia, the range of values for total acidity was found between 5.6 mg CaCO3 / L and 10 mg CaCO3 / L, and an average of 7.03 mg CaCO3 / L. The behavior of the alkaline substances differed, reporting concentrations between 56 mg / L and 113 mg / L with an average of 71.28 mg / L.

With respect to the results obtained for the parameters of acidity and alkalinity, it can be observed that there is a greater capacity of water to neutralize acidic substances present in seawater. The behavior of these two parameters can be seen in Figure No. 5.178.

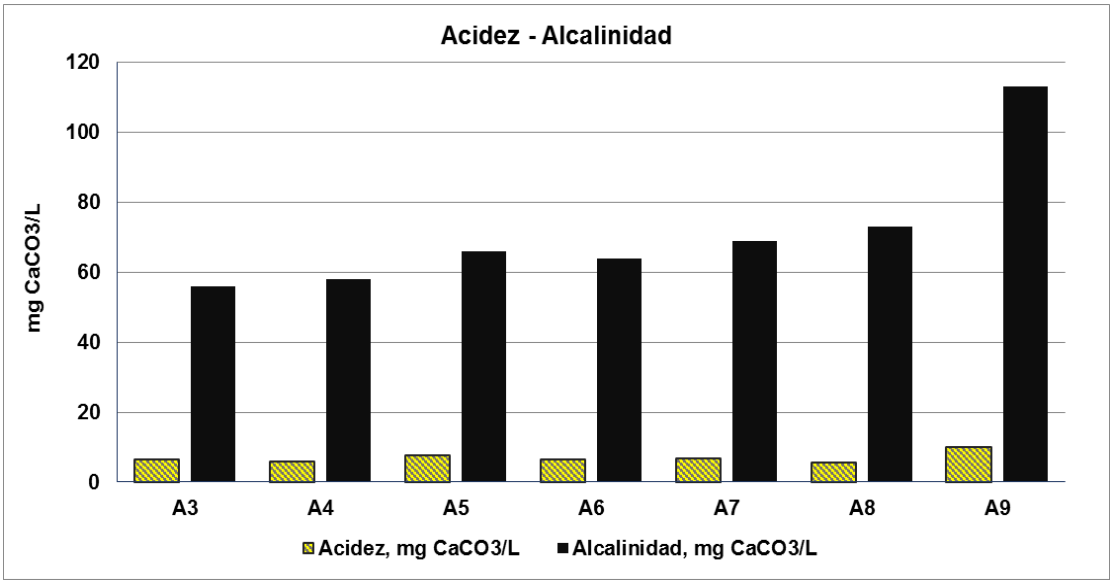


Figure No. 5.159 Acidty and Alkalinity Behavior
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Total hardness

The total hardness determined in the sampling stations in Bahía Colombia yielded considerably high values, which allows establishing that there is an abundance of compounds associated with the Ca ++ and Mg + ions. The range in which the values of this parameter are found ranges from 977 mg CaCO3 / L to 4,130 mg CaCO3 / L, with an average of 2641 mg CaCO3 / L. As part of the total hardness, the calcium hardness reported in proportion values representing approximately 50% of the total hardness, with a concentration range of 748 mg CaCO3 / L to 3470 mg CaCO3 / L, and an average of 1,791.1 mg CaCO3 / L. (See Figure No. 5.179)

The station that reported the highest values of total hardness and calcium hardness was A9, with 4,130 mg CaCO3 / L and 3,470 mg CaCO3 / L, respectively. On the other hand, the station with the lowest concentrations of total hardness and calcium hardness was A3, with values of 977 mg CaCO3 / L and 478 mg CaCO3 / L, respectively.

In relation to the above, a relationship of total hardness with alkalinity can be established, since when presenting lower values, the latter can be mostly represented by carbonate compounds associated with calcium, which according to the pH could be mainly bicarbonates

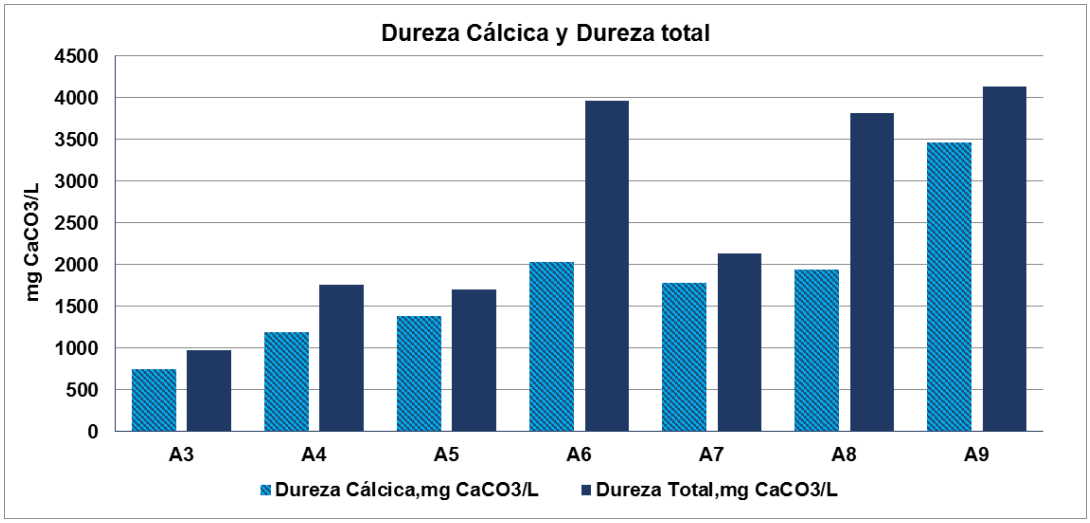


Figure No. 5.160 Total Hardness Behavior and Calcium Hardness
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ True Color

Physical parameters of water such as true color and turbidity, reported important values, as well as similar among 6 (six) of the 7 (seven) monitored points, as can be seen in Figure No. 5.180 and Figure No. 5.181 .

The true color presented values within a range between 13 to 22 UPC and an average of 17 UPC, with the highest value in the A3 station. The above is consistent with the results obtained for turbidity, since for the true color analysis, the samples are filtered, removing the solids suspended from the water, the dissolved solids remaining.

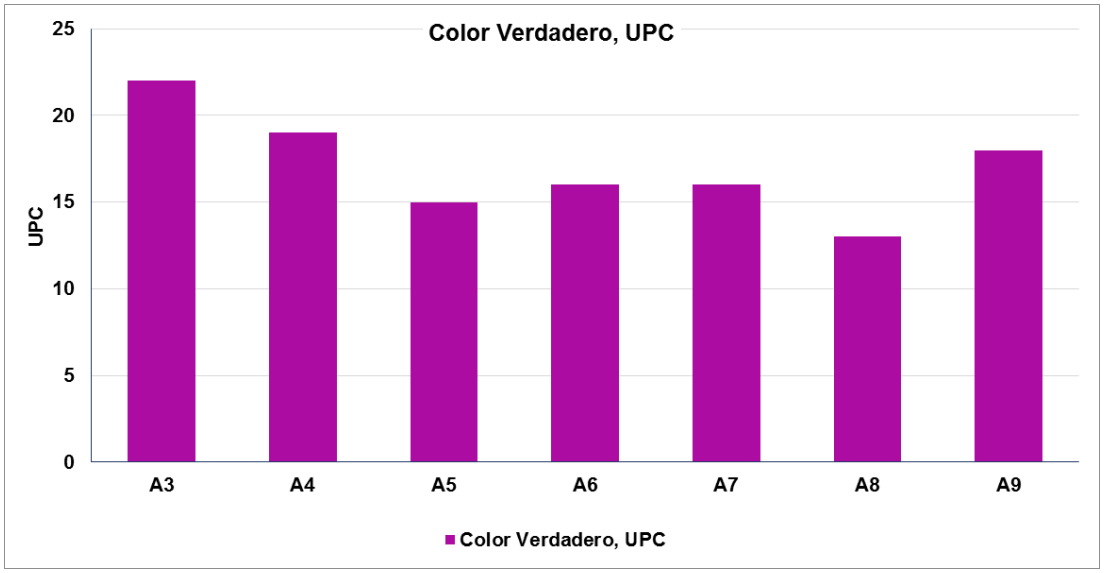


Figure No. 5.161 True Color Behavior – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Turbidity

Regarding the turbidity reported in Bahía Colombia, the values oscillated between 2.01 NTU and 42.3 NTU with an average of 9.66 NTU, the latter reported in the A3 station, which reduces water transparency. It can be seen that the behavior of the turbidity is similar to the behavior of the true color, since for the points A4, A5, A6, A7, A8 and A9 the variability in the values is not representative. According to the location of the A3 station, the turbidity and true color in the sea water can be associated by the proximity of the mouth of the León River to Bahía Colombia, which contributes different pollutants that are swept away by the currents and climatic conditions of the zone (see Figure No. 5.181).

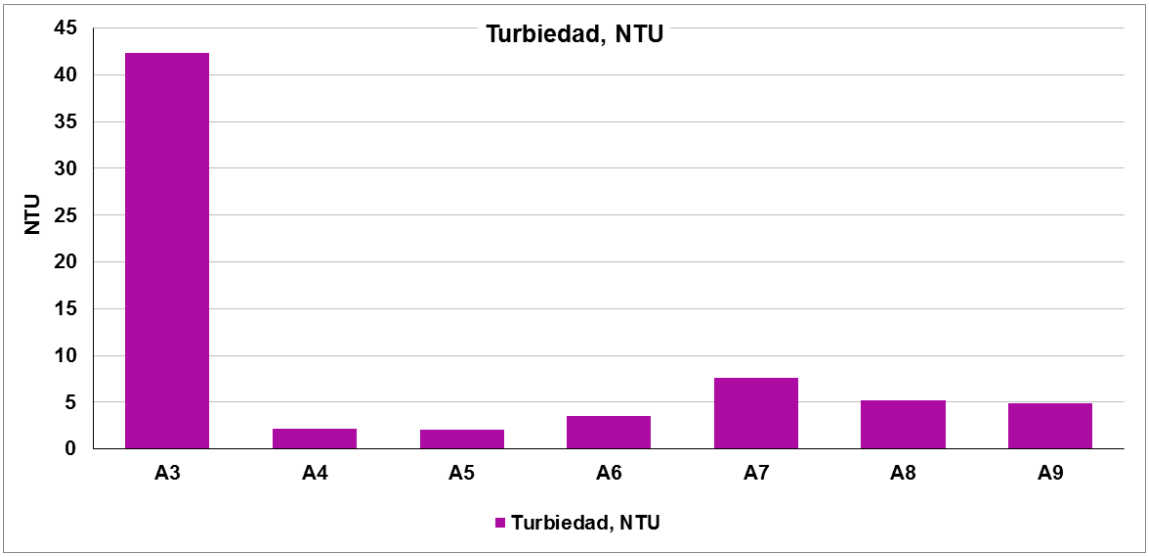


Figure No. 5.162 Turbidity behavior – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand(COD)

According to the results of marine water quality in Bahía Colombia, Biochemical Oxygen Demand (BOD) reported values within a range of <2 mg O2 / L, (stations A4, A5, A6 and A9) up to 10 mg / L O2 (stations A3 and A7), meanwhile station A8 reported a value of 4.5 mg O2 / L. In general, the behavior of this parameter is not unfavorable, since there were no significant variations in the results obtained.

Regarding the Chemical Oxygen Demand (COD), values were reported between <10 mg / L O2 at 24 mg / L O2. In most of the stations, values lower than the limit of detection of the analytical technique used by the laboratory (<10 mg / L O2) were recorded, as is the case of A4, A5, A6 and A9, keeping this agreement with the parameter previous; Station A8 reported a value of 11 mg / L O2. The stations with the highest oxygen demands were A3 and A7 that reported 24 mg / L O2 and 23 mg / L O2, associated with the presence of organic substances that require chemical oxidation for their degradation, probably synthetic compounds, whose natural degradation can demand long periods of time (see Figure No. 5.182).

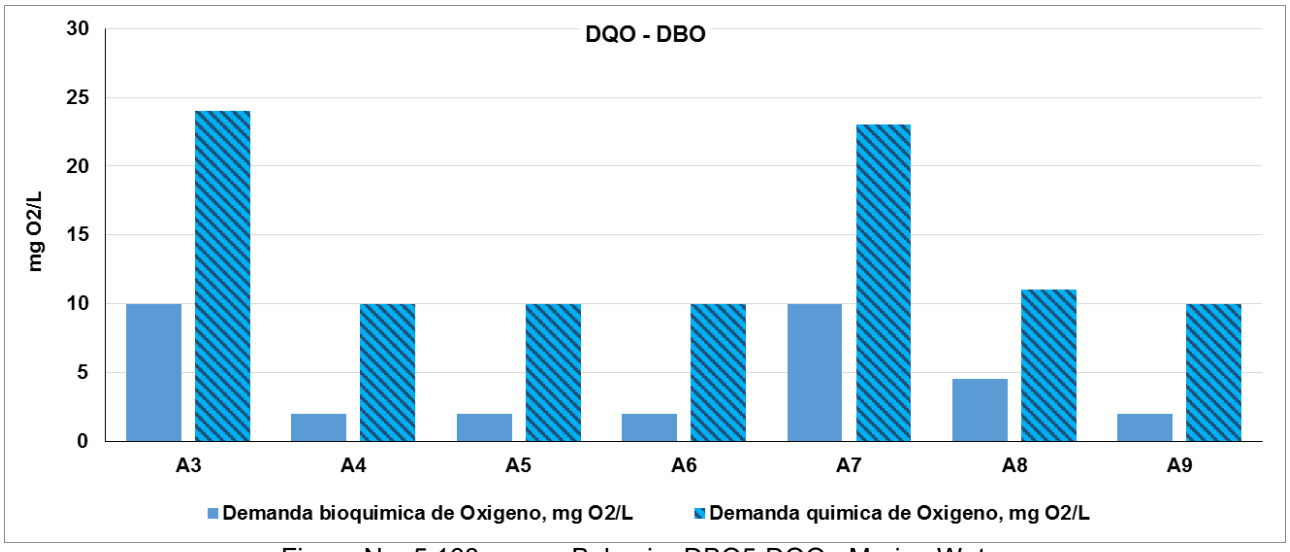


Figure No. 5.163 Behavior DBO5-DQO– Marine Water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

- **Detergents, Total Phenols, Total Nitrogen, Fats and Oils and Polynuclear Aromatic Hydrocarbon**

Parameters such as Detergents, Total Phenols, Total Nitrogen, Fats and Oils and Polynuclear Aromatic Hydrocarbons, reported concentrations lower than the limit of detection of the analytical technique used by the laboratory, in all the sampling stations evaluated in the Bahía Colombia sector in the Gulf of Mexico. Urabá, as can be seen in Table No. 5.62, so it can be inferred that the presence of these pollutants in seawater in this study area is very low, whose concentrations are of the order of the traces and do not generate affectation of the physicochemical and microbiological characteristics of water.

Regarding regulatory compliance, Decree 1076 of 2015, Chapter 3, Section 9 only establishes a permissible limit for total phenols in article 2.2.3.3.9.7 (Quality criteria for recreational purposes through primary contact) in what refers to this parameter, allowing to establish its total compliance.

COLOMBIA. MINISTRY OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. Decree 1076 (May, 26, 2015). Op Cit.

❖ Total phosphorus

Total Phosphorus is generally found in natural waters such as Phosphates; which is used by plants for their development, but if they are found in excessive amounts they induce the excessive growth of algae and other organisms causing the eutrophication of the waters. The concentrations reported in the marine water points ranged between 0.030 mg / L to 0.2 mg / L, being consistent with the characteristics of the water monitored. It is important to mention that the articles in comparison do not establish restrictions in the presence of these parameters (see Figure No. 5.183).

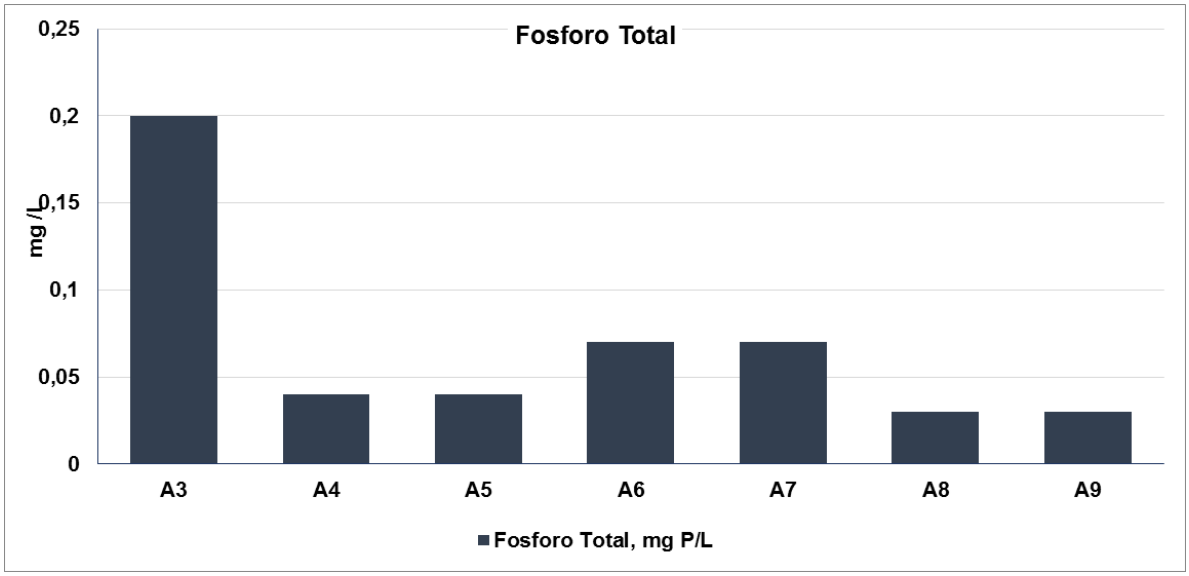


Figure No. 5.164 Total Phosphor Behavior – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Total Dissolved Solids, Total Suspended Solids and Sedimentable Solids

The solids produce alteration in the development of the early stages of the fish, by modifying the natural movements and migration equally, they reduce the abundance of food and affect the primary productivity of the system.

Total suspended solids are considered an indicator of water quality; which are generated naturally and by anthropic activities; the concentrations ranged from 5.1 mg / L to 85 mg / L, the maximum concentration was recorded at the station identified A3 and the minimum at station A5. The results are related to the turbidity of the water, which presented the highest concentration in the A3 station, being this station the closest to the mouth of the León River in Bahía Colombia, which could be associated with the pollutant load that drains the river waters up by the anthropogenic activities and erosion processes of the area (see Figure No. 5.184).

The total dissolved solids include the inorganic salts (mainly calcium, magnesium, potassium and sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in the water. The reported values ranged from 7,390 mg / L to 21,000 mg / L respectively with an average of 13,330 mg / L, to culminate, the sedimentable solids registered in the majority the limit of detection of the analytical technique used for their analysis. The registered behavior is illustrated in Figure No. 5.184. It is important to mention that the parameters in question do not establish a permissible limit in Decree 1076 of 2015.

MINISTRY OF ENVIRONMENT, E. (s.f.) Annex I, Book VI, Environmental Quality. In E. Ministry of Environment, Environmental Quality Standard and Discharge of Effluents. 2001 . 301 - 303 p.
WORLD HEALTH ORGANIZATION -OMS. Guide for the quality of drinking water. 2003. (Online). <http://www.who.int/water_sanitation_health/dwq/gdwq3_es_fulll_lowsres.pdf> (Accessed September 11, 2015)
COLOMBIA. MINISTRY OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. Decree 1076 (May, 26, 2015). Op Cit.

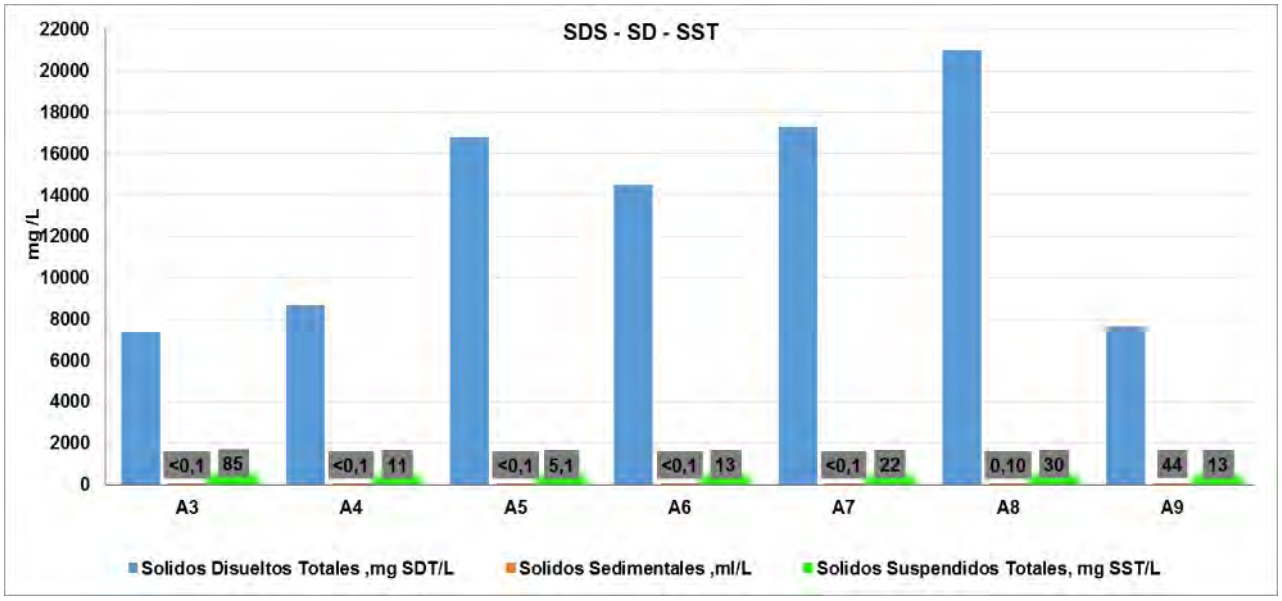


Figura No. 5.165 Behavior Solids – Marine water

Fuente: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Total Coliforms and Fecal Coliforms

Bacteria belonging to the group of total coliforms (excluding E. coli) are present in both wastewater and natural waters. The reported concentrations for total coliforms in Bahía Colombia ranged between 2,489 NMP / 100 ml and values above the limit of quantification of the analytical technique used by the laboratory for its analysis; Regarding the fecal coliforms indicator of contamination of fecal origin, which are a risk to public health when in contact with humans, they recorded concentrations between 1.0 NMP / 100 ml to 4,730,000 NMP / 100 ml; being the maximum concentration in station A9, this behavior is possibly associated with discharges of wastewater to the marine ecosystem and possible contributions of the Atrato River which is the closest station to the mouth of one of the most important rivers in the Gulf of Urabá (see Figure No. 5.185).

Regarding regulatory compliance Total Coliforms exceed the values established in articles 2.2.3.3.9.7 and 2.2.3.3.9.8 of Decree 1076 of 2015, except for the A3 and A4 stations that

registered values lower than article 2.2.3.3.9.8 (Quality criteria for recreational purposes through secondary contact).

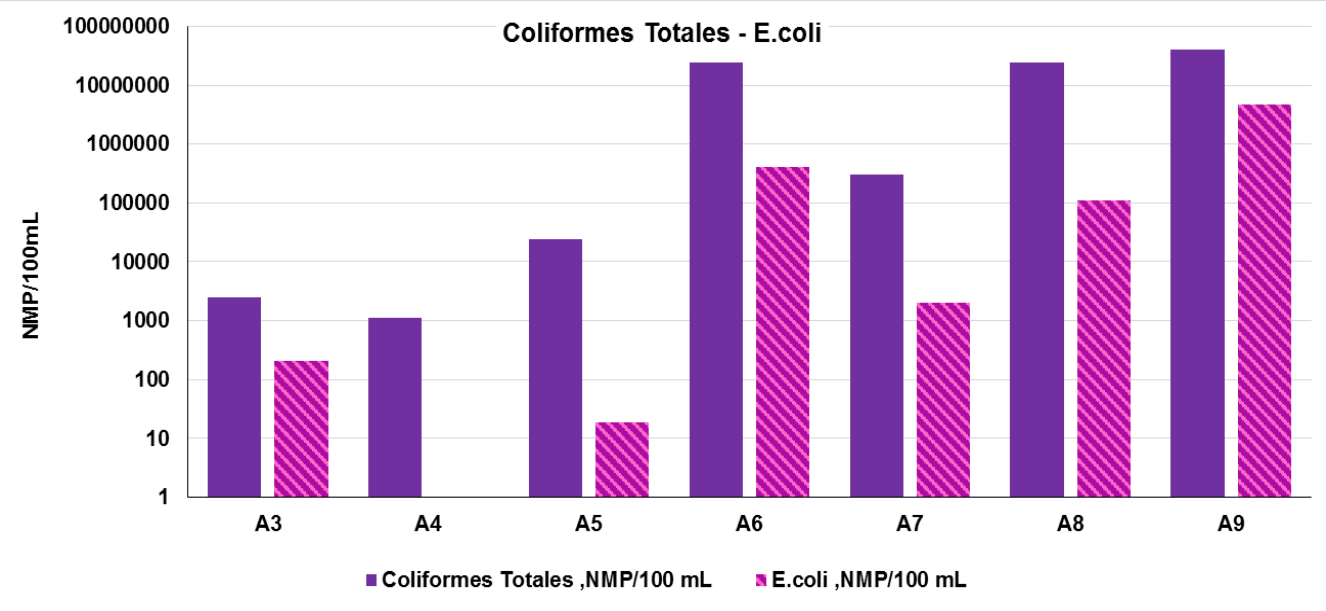


Figure No. 5.166 Behavior Total coliforms and E coli – Marine water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Heavy metal traces

Heavy metals are generally found as natural components of the earth's crust, in the form of minerals, salts or other compounds, they can be absorbed by plants and thus incorporated into trophic chains; move to the atmosphere by volatilization and move to surface or underground water. They are not easily degraded in a natural or biological way since they do not have specific metabolic functions for living beings.

According to the results in Bahía Colombia stations, the heavy metals Barium, Cadmium, Silver and Lead registered concentrations lower than the limit of detection of the analytical technique reaffirming that the presence of these compounds in the seawater is almost nil and does not affect the physicochemical characteristics of the system; in the case of metals such as copper, chromium, nickel, arsenic and mercury, reported low concentrations and in some stations lower than the limit of detection of the analytical technique used by the laboratory.

On the other hand, the Selenium parameter registered concentrations between 0.142 mg / L to 0.39 mg / L and for the case of Zinc registered values ranging from 0.06 mg / L to 0.47 mg / L in Figure No 5.186 and Figure No. 5.187 such behavior is illustrated.

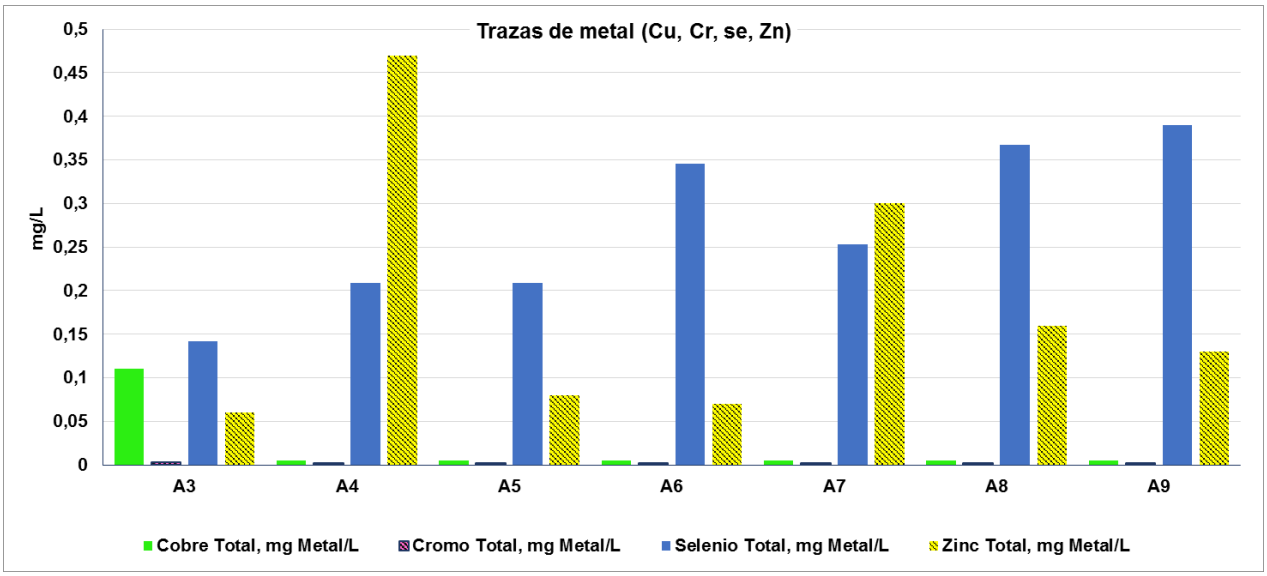


Figure No. 5.167 Metal Behavior – Marine Water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

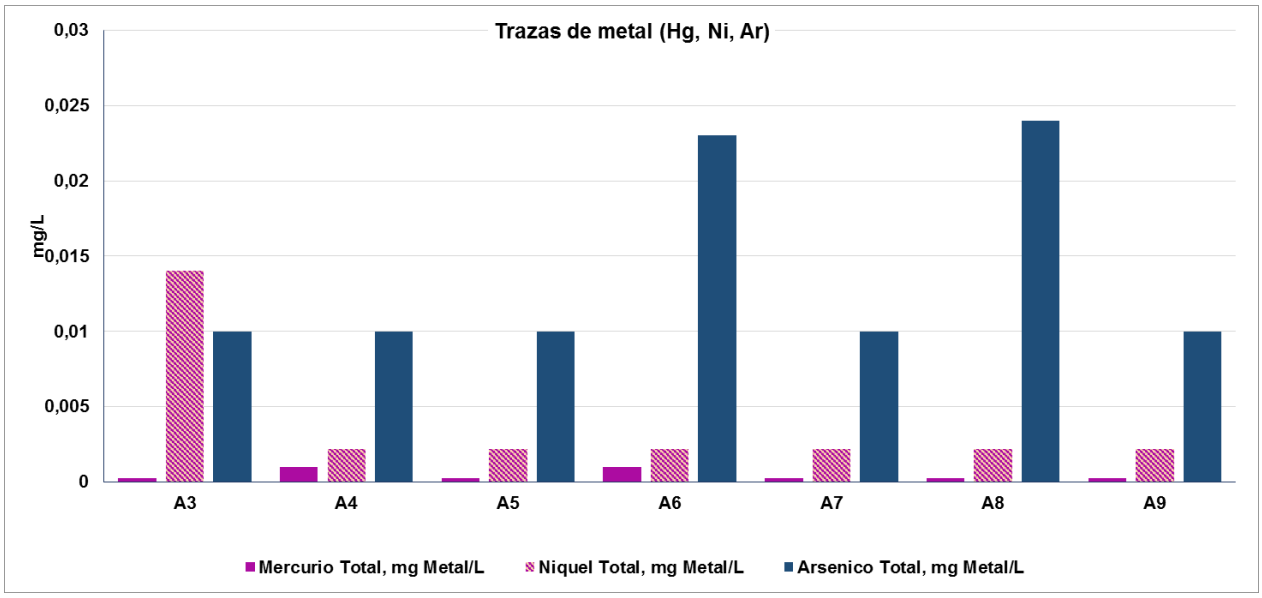


Figure No. 5.168 Metal Behavior – Marine Water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

❖ Chlorophyll

The evaluation of chlorophyll-a content has been an important parameter for a large variety of studies for several years. Works have been carried out, mainly, related to water quality in which the content of chlorophyll-a in estuaries is used as an index of trophic conditions. In addition, there is a large amount of information regarding the use of chlorophyll-a concentrations to estimate the primary productivity of marine ecosystems, Chlorophyll A concentrations ranged from 1.13 mg / m3 to 19.1 mg / m3, for In the case of Chlorophyll B, a value was recorded between 1.84 mg / m3 and 31.2 mg / m3 respectively. This behavior is illustrated in Figure No. 5.188.

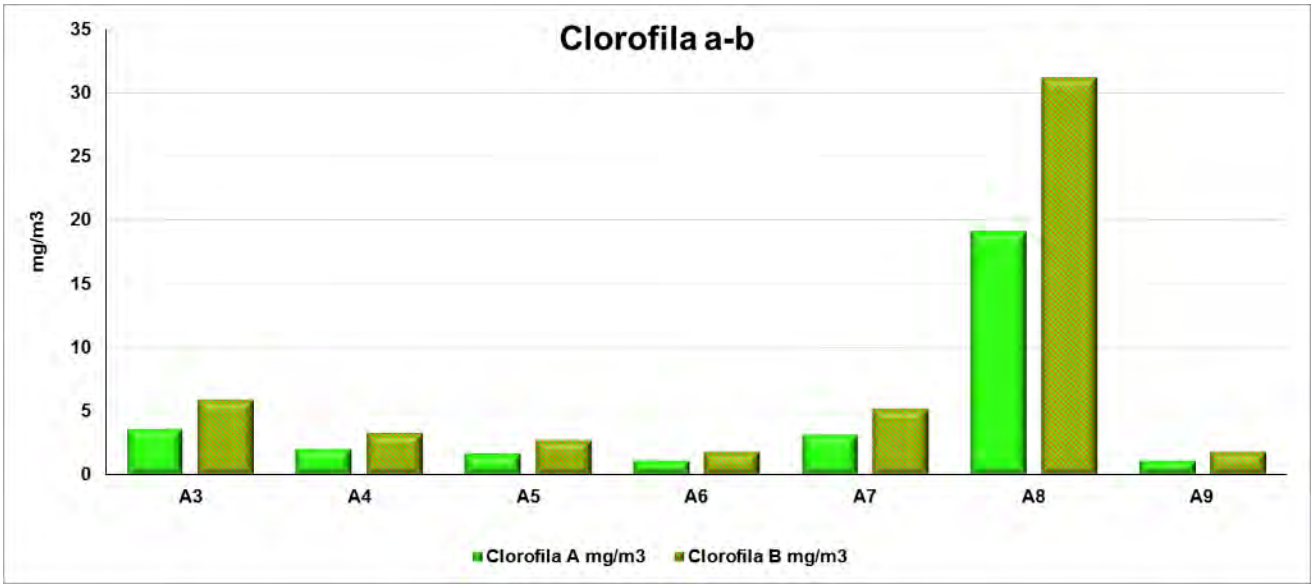


Figure No. 5.169 Chlorophyll Behavior – Marine Water
Source: Aqua & Terra Consultores Asociados S.A.S., 2015 with results from SGS S.A.S, 2015

- Comparison with the national and international standard

❖ **National Standard – Decree 1076 de 2015**

The comparison was made with Colombian regulations, where it establishes the permissible limits of the quality of the marine or estuarine water for the destination of the resource in different uses, in accordance with Decree 1076 of 2015, which is a Regulatory Single Decree of the Environmental Sector and Sustainable Development, in Chapter 3, Section 9 Transitory provisions for water uses and quality criteria for uses, in the following articles:

- Article 2.2.3.3.9.7. Recreational purposes – primary contact.
- Article 2.2.3.3.9.8. Recreational purposes – secondary contact.
- Article 2.2.3.3.9.10 Quality criteria for the preservation of vegetation and wildlife

Table No. 5.63 and Table No. 5.64 present the results of the physicochemical and bacteriological parameters that apply to the aforementioned articles, for the destination of the resource for recreational purposes and for the preservation of wildlife and vegetation.

Table No. 5.57 Comparison of the results with the norm – Point A3 - A4 – A5- A6-

ANALYSIS	Results				Decree 1076 of 2015			FULFILLMENT
					Art. 2.2.3.3.9.7	Art. 2.2.3.3.9.8	Art. 2.2.3.3.9.10	
	A3	A4	A5	A6	Recreational purposes - Primary contact	Recreational purposes - secondary contact	Preservation of Flora and Fauna	
pH, units	6,69	7,08	6,84	7,79	5,0 - 9,0	5,0 - 9,0	6,5 - 8,5	Comply
Dissolved Oxygen, mg / L	6,67	7,64	7,54	7,02	N.E.	N.E.	> 4,0	Comply
% Saturation Dissolved Oxygen *	86,8	100,6	98,6	90,4	70%	70%	N.E.	Comply
Total coliforms, NMP / 100 ml *	2.489	1.119,9	>VNTC **	>VNTC **	1000	5000	N.E.	A3 y A4 Do not Comply Art. 2.2.3.3.9.7. A5, A6 Does not meet any item

* Determined for an altitude of 2 masl and the respective measurement in the field of Temperature and Dissolved Oxygen** >VNTC : Very numerous to count . The result is >24196.
N.E.: Not Specific
Source: SGS Colombia S.A.S (July 2015)

Table No. 5.58 Comparison of the results with the norm – Point A7- A8 – A9

ANALYSIS	Results			Decree 1076 of 2015			FULFILLMENT
				Art. 2.2.3.3.9.7	Art. 2.2.3.3.9.8	Art. 2.2.3.3.9.10	
	A7	A8	A9	Recreational purposes - Primary contact	Recreational purposes - secondary contact	Preservation of Flora and Fauna	
pH, units	7,58	7,56	8,10	5,0 - 9,0	5,0 - 9,0	6,5 - 8,5	Comply
Dissolved Oxygen, mg / L	7,52	7,50	7,48	N.E.	N.E.	> 4,0	Comply
% Saturation Dissolved Oxygen *	97,0	96,9	97,5	70%	70%	N.E.	Comply
Total coliforms, NMP / 100 ml	307.600	>VNTC**	41060000	1000	5000	N.E.	Does not Comply

* Determined for an altitude of 2 masl and the respective measurement in the field of Temperature and Dissolved Oxygen** >VNTC : Very numerous to count >24196. Dilution 10-3
N.S .: Not Specific Source : SGS Colombia S.A.S (July 2015)

From the previous results, it can be concluded that the quality of the marine water in Bahía Colombia in the stations analyzed for the study area of the project, complies with what is stipulated for the destination of the resource for the preservation of flora and fauna in accordance with the stipulated in Article 2.2.3.3.9.10 of Decree 1076 of 2015. This indicates that the current quality of seawater does not present unfavorable conditions for aquatic life.

However, the concentrations of total coliforms in marine water exceed the permissible limits for the destination of the resource for recreational purposes with primary and secondary contact (Articles 2.2.3.3.9.7 and 2.2.3.3.9.8 of Decree 1076 of 2015), The results were expected, given that Bahía Colombia is influenced by discharges from the channels such as the Atrato River and the León River, which are important tributaries in the area that contain human settlement discharges without previous treatment, it is also an area where the agriculture type export that by runoff polluting arrive at the bay.

- **International Standards**

Given that Colombian regulations do not establish permissible limits for some parameters, the analysis of the quality of marine or estuarine water was made, especially for metals with the Canadian and Ecuadorian standards:

- The Canadian Water Quality Guidelines for the Protection of Aquatic Life Protection
- The Standard for Environmental Quality and Effluent Discharge: Water Resource - Book VI Annex 1 (TULAS- Ecuador).

In Table No. 5.65 Table No. 5.63 and Table No. 5.66, the results of the physicochemical parameters are presented, especially the metal traces that apply to the aforementioned standards, for the destination of the resource as for the prevention of wildlife and vegetation and the protection of aquatic life.

Table No. 5.59 Comparison of the results with the foreign standards of reference - A3, A4 - A5 y A6

ANALYSIS	Results				Environmental Quality Standard and Download TULAS- Marine and estuary water	Canadian Standard Protection of Aquatic Life Long term	FULFILLMENT
	A3	A4	A5	A6	Use of Fauna and Flora Preservation		
Total bar, mg Metal / L	<0,0855	<0,0855	<0,0855	<0,0855	1,0	N.E.	They comply
Total Cadmium, mg Metal / L	<0,002	<0,002	<0,002	<0,002	0,005	0,00012	They comply TULAS. With respect to Canadian Standard it is not determined. **
Total Copper, mg Metal / L	0,11	<0,0049	<0,0049	<0,0049	0,05	N.E.	A4 - A5-A6 Meet Standards TULAS. A3 Does not Comply Standards TULAS.
Total Chromium, mg Metal / L	0,003	<0,0026	<0,0026	<0,0026	0,05	N.E.	They comply standards **TULAS**
Mercury Total, mg Metal / L	<0,00027	0,001	<0,00027	0,001	0,0001	0,000016	A4, A6 Do not Comply Canadian Standard A4, A6 Do not Meet Standard TULAS.
Total Nickel, mg Metal / L	0,014	<0,0022	<0,0022	<0,0022	0,1	N.E.	They meet standards TULAS
Total Silver, mg Metal / L	<0,0004	<0,0004	<0,0004	<0,0004	0,005	N.E.	They meet standards TULAS
Total Lead, mg Metal / L	<0,004	<0,004	<0,004	<0,004	0.01	N.E.	They meet standards TULAS
Selenium Total, mg Metal / L	0,142	0,209	0,209	0,346	0,01	N.E.	Does not comply TULAS
Total Arsenic, mg Metal / L	<0,010	<0,010	<0,010	0,023	0,05	0,0125	A3, A4, A5 y A6 They Comply TULAS A6 Does not Meet Canadian Standard
Total Zinc, mg Metal / L	0,06	0,47	0,08	0,07	0,17	N.E.	A4 Does not comply TULAS.
Fats and Oils, mg GyA / L	<0,8	<0,8	<0,8	<0,8	0,3	N.E.	Not Determined

** The limit of detection of the analytical technique is greater than the normative limit, therefore it cannot be determined whether the parameter meets or not.
Source: SGS Colombia S.A.S (July 2015)

Table No. 5.60 Comparison of the results with the foreign standards of reference – A7 -A8 y A9

ANALYSIS	Results			Environmental Quality Standard and Download TULAS	Canadian Standard Protection of Aquatic Life Long term	FULFILLMENT
	A7	A8	A9	Use of Fauna and Flora Preservation		
Total bar, mg Metal / L	<0,0855	<0,0855	<0,0855	1,0	N.E.	Cumplen Norma TULAS
Total Cadmium, mg Metal / L	<0,002	<0,002	<0,002	0,005	0,00012	Cumplen Norma TULAS No Determinado Norma Canadiense
Total Copper, mg Metal / L	0,005	<0,0049	<0,0049	0,05	N.E.	Cumplen Norma TULAS
Total Chromium, mg Metal / L	<0,0026	<0,0026	<0,0026	0,05	N.E.	Cumplen Norma TULAS
Mercury Total, mg Metal / L	<0,00027	<0,00027	<0,00027	0,0001	0,000016	No Determinado
Total Nickel, mg Metal / L	<0,0022	<0,0022	<0,0022	0,1	N.E.	Cumplen
Total Silver, mg Metal / L	<0,0004	<0,0004	<0,0004	0,005	N.E.	Cumplen
Total Lead, mg Metal / L	<0,004	<0,004	<0,004	0,01	N.E.	Cumplen
Selenium Total, mg Metal / L	0,253	0,367	0,39	0,01	N.E.	No Cumplen Norma TULAs
Total Arsenic, mg Metal / L	<0,010	0,024	<0,010	0,05	0,0125	A7, A8 y A9 Cumplen Norma TULAS A8 No Cumplen Norma Canadiense
Total Zinc, mg Metal / L	0,30	0,16	0,13	0,17	N.E.	A7 No Cumplen Tulas
Fats and Oils, mg GyA / L	<0,8	<0,8	<0,8	0,3	N.E.	No Determinado

** The limit of detection of the analytical technique is greater than the normative limit, therefore it cannot be determined whether the parameter meets or not.
Source: SGS Colombia S.A.S (July 2015)

- Index of marine and coastal water quality – IMWQ

According to the information obtained in the analysis results of the seasons sampled in Bahía Colombia, some parameters were used to calculate the Marine and Coastal Water Quality Index - IMWQ which is a statistical tool that allows to evaluate the changes in the state of the quality of the marine and coastal water, by means of an algebraic equation that qualifies each parameter by means of the adjusted curves, giving rise to the indicator applied to Marine Water Substrate, according to the methodology presented in Chapter 2 General of the present study.

In this sense, Table 5.67 to Table No. 5.73 presents the results obtained in the adjusted curves for each parameter and the indicator applied to Marine Water Substrate for each sampling station in Bahía Colombia in the Gulf of Urabá.

It is worth mentioning that for the calculation of the index, the eight (8) parameters required for the calculation were not counted for a 100% reliability, however the index was calculated with four (4) parameters such as dissolved oxygen, suspended solids total, pH and BOD, for a reliability of the result of 53%. The other parameters such as thermotolerant coliforms, phosphates, nitrates and dissolved and dispersed hydrocarbons were not requested from the laboratory, since these parameters were not required by the terms of reference for the project.

Table No. 5.61 Indicator Analysis Results - Station A3.

Station A3					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	6,67	86,13	Adequate	**9,28 TERRIBLE**
Total Suspended Solids	mg/L	85	40,05	Inadequate	
pH	Units	6,69	55,07	Acceptable	
BOD	mg/L	10,0	0,03	Terrible	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.62 Indicator Analysis Results - Station A4.

Station A4					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,64	96,07	Optimal	**77,66 ADEQUATE**
Total Suspended Solids	mg/L	11	85,94	Adequate	
pH	Units	7,08	75,74	Adequate	
BOD	mg/L	2	55,72	Acceptable	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.63 Indicator Analysis Results - Station A5.

Station A5					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,54	95,23	Optimal	**75,51 ADEQUATE**
Total Suspended Solids	mg/L	5,1	92,03	Optimal	
pH	Units	6,84	63,19	Acceptable	
BOD	mg/L	2,0	55,72	Acceptable	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.64 Indicator Analysis Results - Station A6.

Station A6					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,02	90,14	Optimal	**79,93 ADEQUATE**
Total Suspended Solids	mg/L	13	84,06	Adequate	
pH	Units	7,79	95,73	Optimal	
BOD	mg/L	2,0	55,72	Acceptable	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.65 Indicator Analysis Results - Station A7.

Station A7					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,52	95,05	Optimal	**12,49 TERRIBLE**
Total Suspended Solids	mg/L	22	76,32	Adequate	
pH	Units	7,58	93,82	Optimal	
BOD	mg/L	10,0	0,03	Terrible	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.66 Indicator Analysis Results - Station A8.

Station A8					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,50	94,88	Optimal	**38,95 INADEQUATE**
Total Suspended Solids	mg/L	30	70,24	Adequate	
pH	Units	7,56	93,44	Optimal	
BOD	mg/L	4,5	3,37	Terrible	

Source: SGS Colombia S.A.S (July 2015)

Table No. 5.67 Indicator Analysis Results - Station A9.

Station A9					
Parameter	**Units**	**Result**	**Value of Quality**	**Adjusted Value Rating**	**Sum Index**
Dissolved oxygen	mg/L	7,48	94,7	Optimal	**80,21 ADEQUATE**
Total Suspended Solids	mg/L	13	84,06	Adequate	
pH	Units	8,10	91,03	Optimal	
BOD	mg/L	2,0	55,72	Acceptable	

Source: SGS Colombia S.A.S (July 2015)

According to the results obtained when calculating the Marine Water Quality Index (IMWQ), it was evidenced that of the seven (7) samples evaluated, two (2) of these obtained a TERRIBLE quality indicator (A3, and A7), one (1) obtained an INADEQUATE classification (A8) and finally four (4) obtained an ADEQUATE classification, as can be seen in Figure No. 5.189.

On the other hand, the analysis allows us to affirm that the most relevant parameter, due to inadequate concentrations, was the Oxygen Biochemical Demand and total suspended solids, which could be associated with organic contamination and sediments, probably due to domestic discharges and trawls. Sediments made to the bay from the Atrato and León rivers, these being the main tributaries in Bahía Colombia. However, these results of the index have a reliance of 53% for the quantity of variables analyzed for the calculation of said index, since not all the concentrations of the variables required for a 100% reliance were available.

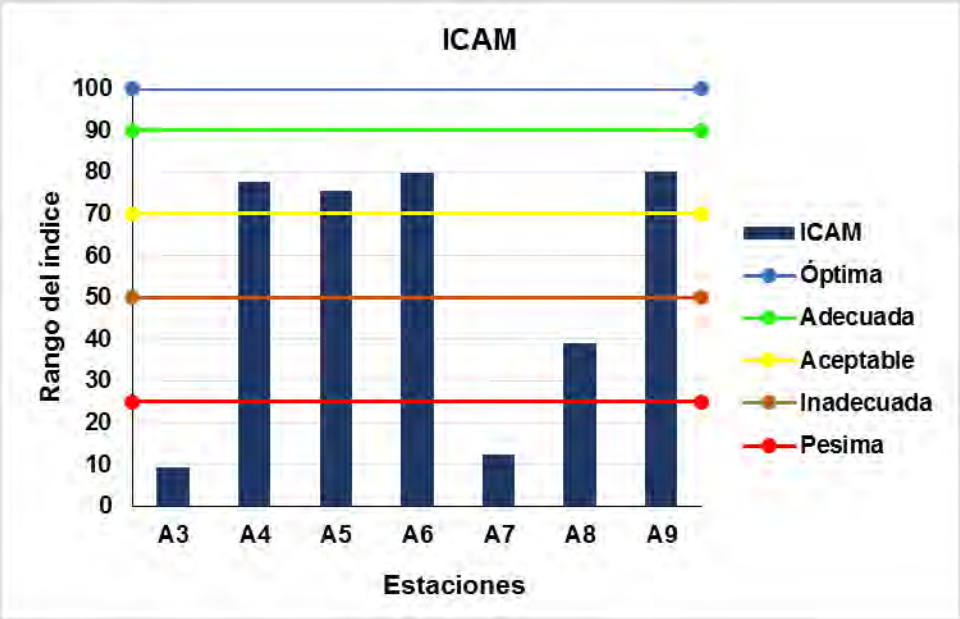


Figure No. 5.170 Marine and Coastal Water Quality Index – MCWQI
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

- *Quality of marine sediments*

The monitoring of seabed sediment quality was done on July 7, 2015 in seven monitoring stations (named A3 to A9) located in Bahía Colombia in the coordinates shown in Table No. 5.14 and in Figure No. 5.172.

- Results obtained from marine sediment quality

The physicochemical parameters evaluated for the characterization of marine sediments (fine fraction of sediment, first 5 cm) correspond to those established in the terms of reference for the preparation of the Environmental Impact Study – EIS in construction projects or expansion and operation of ports maritime projects (MM-INA-05).

The results of the evaluated parameters are presented below in Table No. 5.74:

Table No. 5.68 Results measurement of marine sediment parameters

PARAMETER	Results of the sampling stations						
	A3	A4	A5	A6	A7	A8	A9
Total Organic Carbon, mg C / kg	1261	8999	11365	11233	12084	8894	9053
Total phosphorus	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Granulometry, Mesh N°. 10,%	0,00	51,11	57,75	59,00	58,39	33,19	30,05
Granulometry, Mesh N°. 120,%	0,00	29,30	22,47	22,00	20,13	20,44	20,65
Granulometry, Mesh N° 25, %	1,01	12,85	10,36	10,48	10,97	12,32	11,61
Granulometry, Mesh N° 325, %	71,70	1,32	3,88	3,83	4,41	18,04	22,71
Granulometry, Mesh N° 60, %	24,37	4,27	4,24	3,69	4,67	10,68	10,36
Granulometry, Mesh N° 325 % What passes the mesh	2,92	1,15	1,30	1,00	1,43	5,33	4,62
Fats and Oils, mg GYA / Kg	24	6	10	8	6	13	8
Total Hydrocarbons, mg / kg	5	5	12	10	7	12	9
Total Nitrogen, mg / Kg	733	2790	2070	2270	1730	1680	1690
pH, Units	7,43	7,22	7,28	7,17	7,22	6,92	6,97
Arsenic, mg As / Kg	9,60	15,50	15,20	12,80	15,80	17,40	16,20
Barium, mg Ba / Kg	75,70	120,60	76,70	136,20	108,50	114,50	116,80
Cadmium, mg Cd / kg	<0,614	<0,614	<0,614	<0,614	<0,614	<0,614	<0,614
Copper, mg Cu / kg	33,3	80,8	91,9	72,8	88,1	93,1	91,0

PARAMETER	Results of the sampling stations						
	A3	A4	A5	A6	A7	A8	A9
Chromium, mg Cr / kg	37,8	80,8	81,1	60,1	79,3	83,6	80,9
Mercury, mg Hg / kg	<0,069	<0,069	<0,069	<0,069	<0,069	<0,069	<0,069
Nickel, mg Ni / Kg	30,5	56,8	62,4	49,7	60,3	63,7	63,2
Silver, mg Ag / Kg	1,4	<0,0066	1,5	<0,0066	<0,0066	<0,0066	<0,0066
Lead, mg Pb / kg	4,1	7,5	8,8	7,1	8,3	9,0	9,1
Selenium, mg Se / Kg	13,2	21,4	22,6	16,1	21,8	24,4	24,8
Zinc, mg Zn / kg	104,4	176,5	218,8	157,0	197,1	209,1	212,4
Polycyclic aromatic hydrocarbons, mg / kg	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Phenols, mg / Kg	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Volatile Acid Sulphide,% P / P	0,001	18,87	16,95	10,00	10,00	9,35	8,550

Source: SGS Colombia S.A.S (July 2015)

- Analysis of sediment results

❖ Granulometry

The granulometric analysis of the marine sediments was carried out with the purpose of determining the environmental quality of the sediments and the concentrations of heavy metals (Ni, Pb, Cd, Cu, Zn) that could affect the marine ecosystem.

The texture, is the parameter that has been most used in sedimentological studies and refers to the size of the particles that make up the sediment, the same that depends on several factors, including its origin and initial size, since these sediments had to have been transported, so their size will depend on the effects of this transport.

The granulometric composition of the marine sediments of the Bahía Colombia sector in the Urabá Gulf was characterized by presenting the groups of textures mentioned in Table No. 5.75 presented below:

Table No. 5.69 Average particle size composition

Classification	Percentage content (%)
Mesh N° 10 : Retiene partículas Mayores a 2000 Micras (Gravas)	41,35
Mesh N° 120: Between 125 and 250 Microns (Fine Sands)	19,28

Classification	Percentage content (%)
Mesh N° 25: Between 710 and 2000 Microns (Very Thick Sands)	9,94
Mesh N° 325: Between 62.5 and 125 Microns (Very Fine Sands)	17,98
Mesh N° 60 : Between 250 and 710 Microns (Thick Sands and Medium Sands)	8,89
What happens in the Mesh N° 325 corresponds to Limo and Clay	2,5

Source: SGS Colombia S.A.S (July 2015)

The granulometric composition of the marine sediments in the area of influence of the project makes it possible to demonstrate that the most representative component of the total of the samples were particles greater than 2000 microns (Gravel) with a proportion of 41.35%, followed by 19.28 % of fine sands and in third place the very fine sands were found with a percentage of 17.98% as shown in Figure No. 5.190.

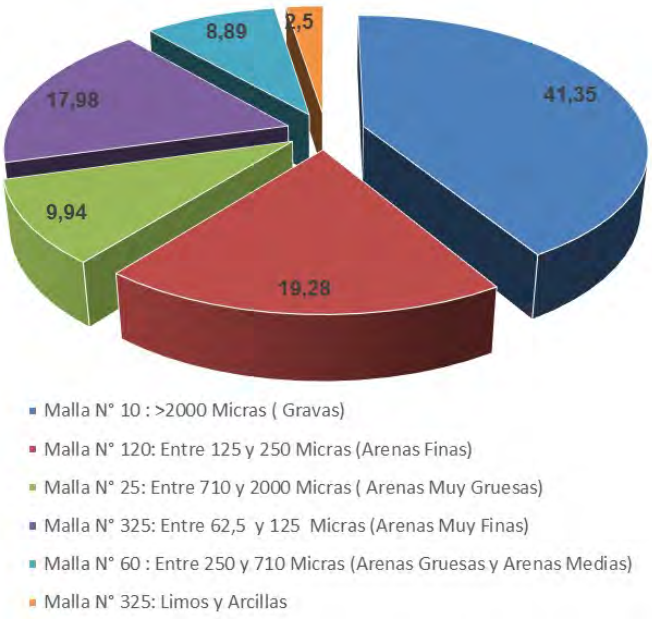


Figura No. 5.171 Content Percentage% granulometric
Source: SGS Colombia S.A.S (July 2015)

Below is the proportion by component in each of the sampling points:

Mesh No. 10, particles> 2000 microns (gravel)

The percentage of gravel (particles greater than 2000 microns) can be formed naturally during the decomposition of organic vegetable and animal sources. The most representative percentage contents were presented in points A4, A5, A6 and A7 as shown in Figure No. 5.191

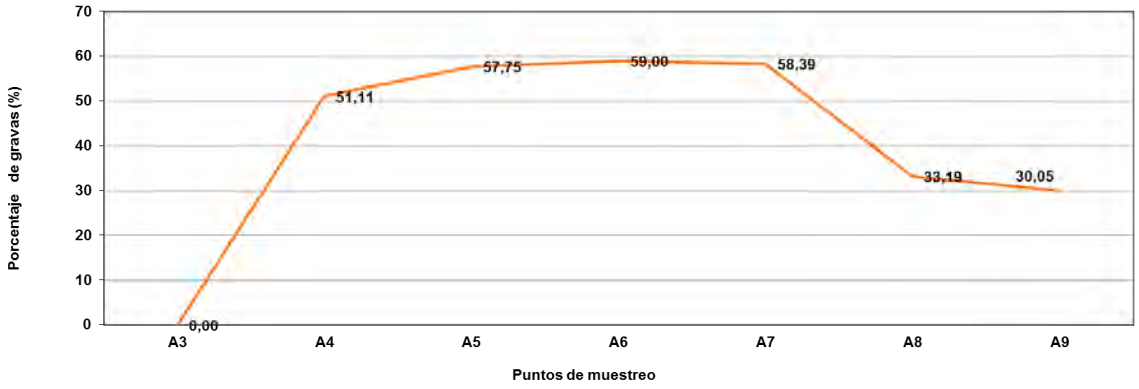


Figure No. 5.172 Behavior Granulometry Mesh N° 10 particles greater than 2000 microns Gravel
Source: SGS Colombia S.A.S (July 2015)

Mesh N° 25, Particles between 710 and 2000 microns (very thick sands)

The coarse sands associated with the fragmentation of rocks and the degree of weathering, had a very homogeneous composition between 12.85% and 10.36% for all points, except point A3 where a value of 1.01 was obtained. %.

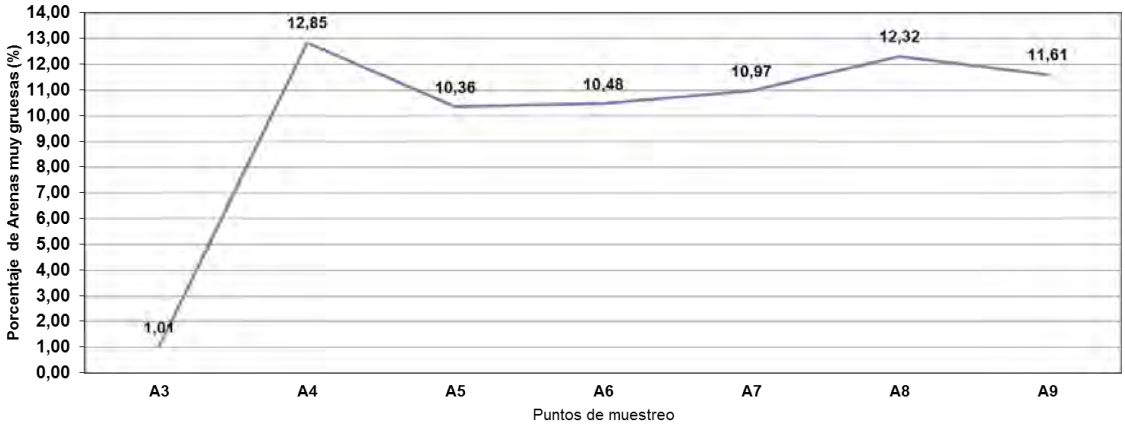


Figure No. 5.173 Mesh N° 25, Particles between 710 and 2000 microns (very thick sands)
Source: SGS Colombia S.A.S (July 2015)

Mesh N°60 Particles between 250 and 710 microns (thick sands and medium sands)

The marine sediments of point A3 (24.37%) are mainly made up of thick sands and medium sand between particles of 250 and 710 microns as shown in Figure No. 5.193.

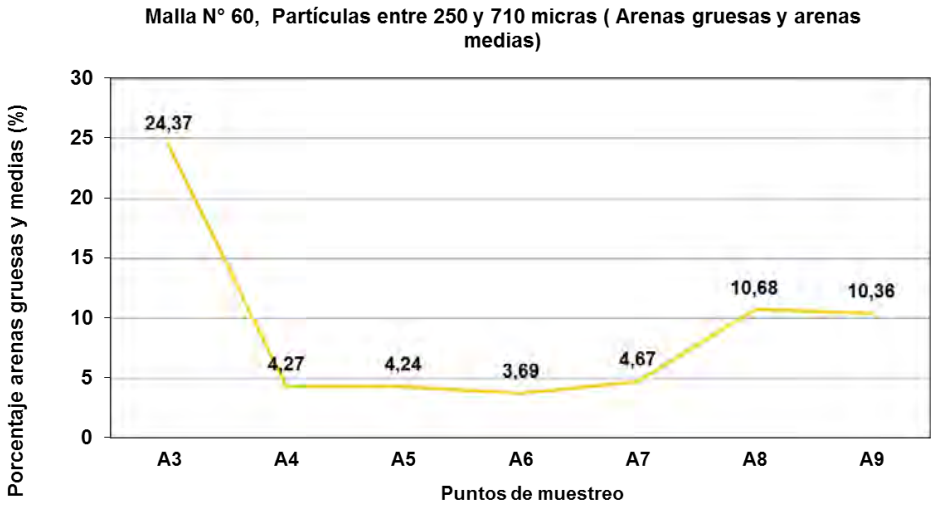


Figure No. 5.174 Mesh N°60 Particles between 250 and 710 microns (thick sands and medium sands)
Source: SGS Colombia S.A.S (July 2015)

Mesh N°120 Particles between 125 and 250 microns (Fine sands)

Regarding the content of fine particles between 125 and 250 microns, the highest percentages are found for 29.30% for A4 and 22.47% for A5, while point A3 recorded the absence of this texture as shown in the Figure No. 5.194.

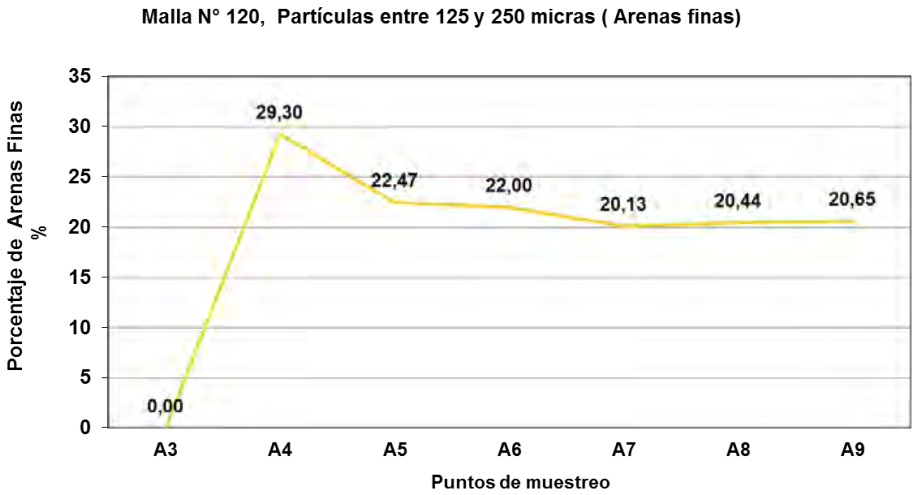


Figure No. 5.175 Mesh N°120 Particles between 125 and 250 microns (Fine sands)
Source: SGS Colombia S.A.S (July 2015)

Mesh N° 325, Particles between 62.5 and 125 microns (very fine sands)

Figure No. 5.195 shows the percentage content of very fine sands, where point A2 recorded a percentage content of 71.70% being the most representative point, while the other points presented contents between 22.71 and 1.32 %.

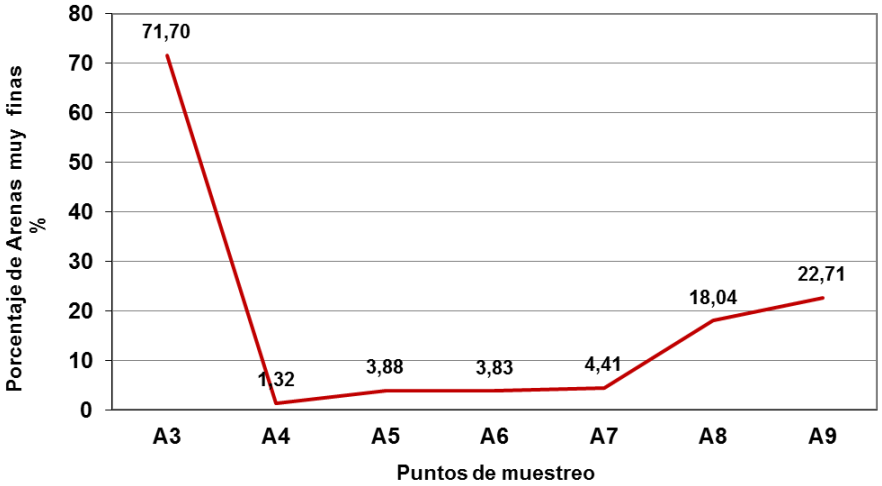


Figure No. 5.176 Mesh N° 325, Particles between 62.5 and 125 microns (very fine sands)
Source: SGS Colombia S.A.S (July 2015)

Mesh N° 325 (Limes and clays)

The highest percentage was identified in point A8 (5.33%) and the lowest in point A6 (1.00%) as seen in Figure No. 5.196

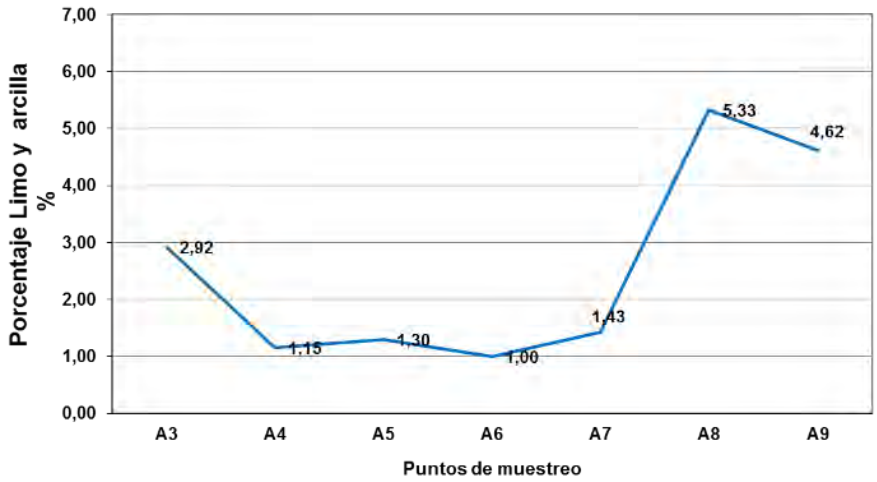


Figure No. 5.177 Mesh 325 (Limo and clay)

Source: SGS Colombia S.A.S (July 2015)

- **Hydrogen potential pH**

The potential of hydrogen is one of the most important chemical properties of the soil because it influences the mobility of ions, dilution of minerals, microbial activities and the availability of nutrients among others. The reported values range from 6.92 Units to 7.43 Units, registering a trend from neutral to moderately basic as shown in Figure No. 5.197.

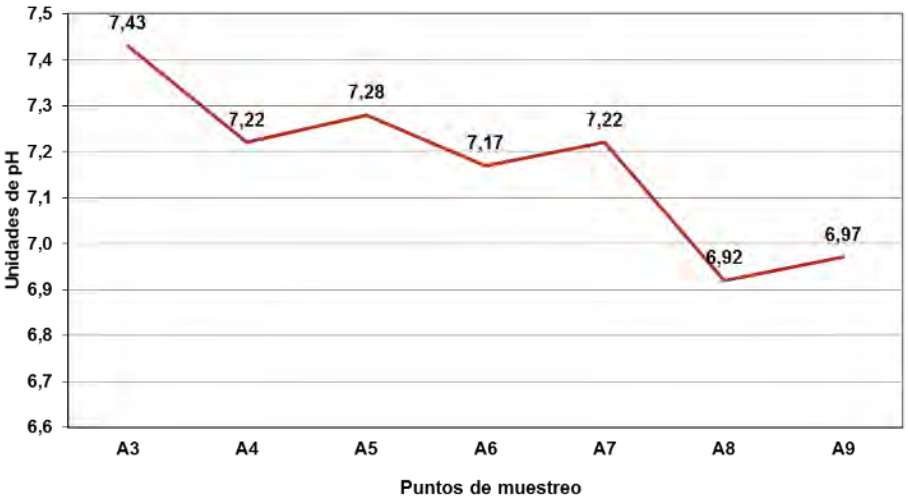


Figure No. 5.178 PH behavior
Source: SGS Colombia S.A.S (July 2015)

❖ Total organic carbon

The edaphic factors that have the greatest influence on the evolution of organic carbon are texture, structure, pH and Redox Potential. The pH affects the organic carbon because this factor decreases the decomposition rates under acidic conditions; while the structure and texture of the soils affect the stabilization of organic carbon in different ways, either through the formation of aggregates, the physical bonding with clay and silt particles and / or by the transformation to resistant carbon compounds to biochemical degradation.

The reported concentrations ranged from 1,261 mg / kg to 12,084 mg / kg, with an average of 8,984 mg / kg. The highest concentrations were registered in points A7 (12,084 mg / kg) and A5 (11,365mg / kg), which is possibly associated with the contributions in Bahía Colombia of the León river and the Atrato river. See Figure No. 5.198.

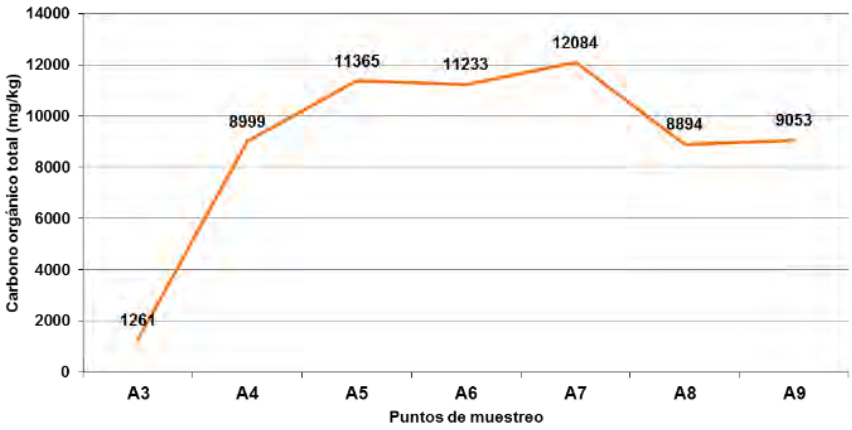


Figure No. 5.179 Total organic carbon behavior
Source: SGS Colombia S.A.S (July 2015)

❖ Total hydrocarbons

The hydrocarbons tend to form associations with the particular material deposited in the sediments and, therefore, the absorption of them is strongly related to the organic carbon content present in the sediments. Other oceanographic factors, such as marine currents, tides and waves can also influence the dynamics of the spatial behavior of hydrocarbons in the area.

According to Saravia, the degree of contamination in the sediments can be established based on the concentration of total hydrocarbons. When the concentration is ≤10 µg / g it is considered without contamination; if the concentration of hydrocarbons is in the range <10 - 100 µg / g, mild to moderate contamination is classified. Finally, if the total hydrocarbon levels are ≥ 100 µg / g, the system is considered to be highly contaminated.

SARAVIA, Ana., RODRIGUEZ, Daniela., PACHECO, Oscar., PIEDRA, Oscar. Evaluation of the levels of hydrocarbons in marine sediments, their possible origin and effects on aquaculture activity between Punta Morales and Costa de Pájaros in the Gulf of Nicoya. In: Geographic Magazine of Central America. Nº 53, ISSN 1011-48X, July-December 2014 pp. 113-134

The concentrations of total hydrocarbons fluctuated between 5 mg / kg to 12 mg / kg, with the highest concentrations at points A5 to A8. According to the Saravia classification, these marine sediments present a mild to moderate contamination and for the rest of the sampling points without contamination, as can be seen in Figure No. 5.199.

For the total hydrocarbons parameter no allowable value is established in the Canadian Sediment Quality Guidelines for the protection of aquatic life.

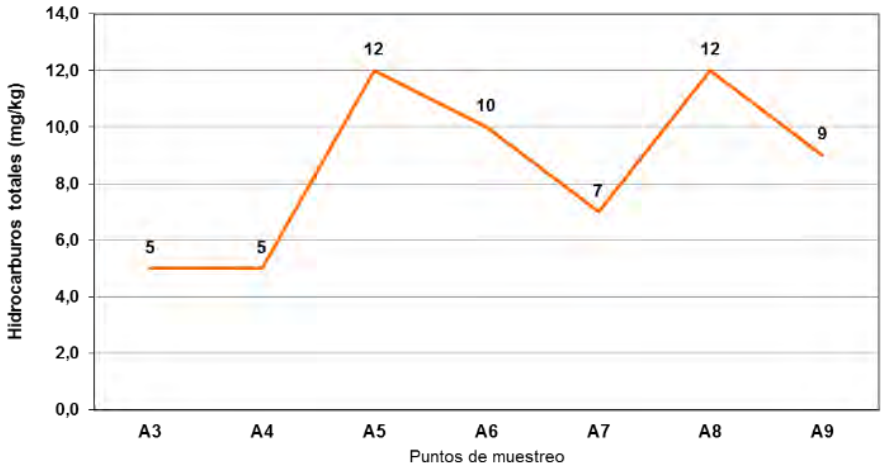


Figure No. 5.180 Total hydrocarbons behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Polycyclic aromatic hydrocarbons (PAHs)

PAHs have become increasingly frequent contaminants in freshwater or marine soils and sediments, mainly due to the dumping of industrial waters, the indiscriminate use of chemical products (pesticides, dyes, industrial solvents, among others) and rainwater and settlement. of particles in the air.

VACA, R. A. Determination of polycyclic aromatic hydrocarbons in soils contaminated by the oil industry. Quito, 2013

The monitored sampling points registered a concentration of PAHs in the sediments below the detection limit of the analytical technique (<0.01 mg / Kg), that is, the presence of these organic compounds in marine sediments is low.

According to the Canadian Sediment Quality Guidelines for the protection of aquatic life, the concentrations found are lower for both the ISQG standard (intermediate standard of sediment quality: concentration below which there are no adverse biological effects) and for the standard PEL (Level of probable effect: Concentration on which adverse biological effects are frequently found) established for the HPA compounds, which are listed in Table No. 5.76.

Table No. 5.70 Standards ISQG and PEL from HPAs

Polycyclic Aromatic Hydrocarbons HPAs	ISGG mg/kg	PEL mg/kg
Naphthalene	0,0346	0,391
2-Methyl naphthalene	0,0202	0,201
Acenaphthylene	0,00587	0,128
Acenafteno	0,00671	0,0889
Fluorene	0,0212	0,144
Anthracene	0,0469	0,245
Fluoranthene	0,113	1,494
Pyrene	0,153	1,398
Fenanthrene	0,0867	0,544
Benz (a) anthracene	0,0748	0,693
Criseno	0,108	0,846
Benzo (a) pyrene	0,0888	0,763
Dibenzo anthracene	0,00622	0,135

Source: Canadian Sediment Quality Guidelines for the protection of aquatic life[218]

[218] CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT – CCME. Canadian water quality guidelines for the protection of aquatic life: Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving Numerical Water Quality Objectives. In: Canadian environmental quality guidelines, 1999. [En línea] < http://ceqg-rcqe.ccme.ca/en/index.html> [Consultado 11, septiembre, 2015]

According to the results shown in Table No. 5.76, it can be established that the concentrations of HPAs in marine sediments do not generate adverse biological effects on the aquatic ecosystem.

aromatic hydrocarbons. It is worth mentioning that for the hydrocarbons Acenaphthylene and Acenofteleno, no comparison can be made because the values are below the limit of detection of the method used.

- **Greases and Oils**

The concentrations of fats and oils reported in marine sediments range between 6 mg / kg and 24 mg / kg; being the maximum concentration in point A3, probably because of its proximity to the area where the León River ends, where industrial and domestic waste can be produced without prior treatment. See Figure No. 5.200

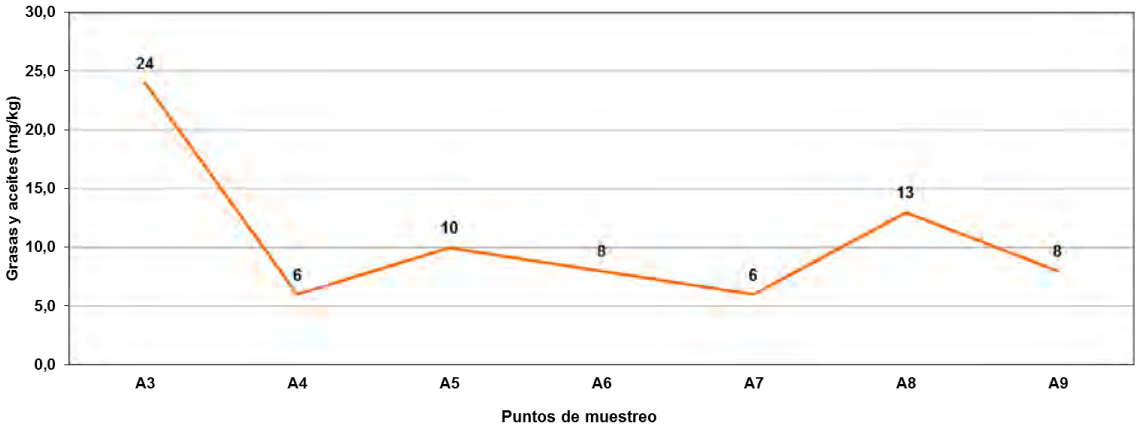


Figure No. 5.181 Fats and oils behavior

Source: SGS Colombia S.A.S (July 2015)

- **Volatile Acid Sulfide**

The concentrations reported in the seven (7) monitoring points fluctuated between 0.001% P / P and 18.87% P / P, meaning that in 100 grams of sediments the maximum percentage of volatile acid sulfide is 18.87 grams, reported in point A4. See Figure No. 5.201.

For this parameter the Canadian Sediment Quality Guidelines for the protection of aquatic life does not have an allowable limit.

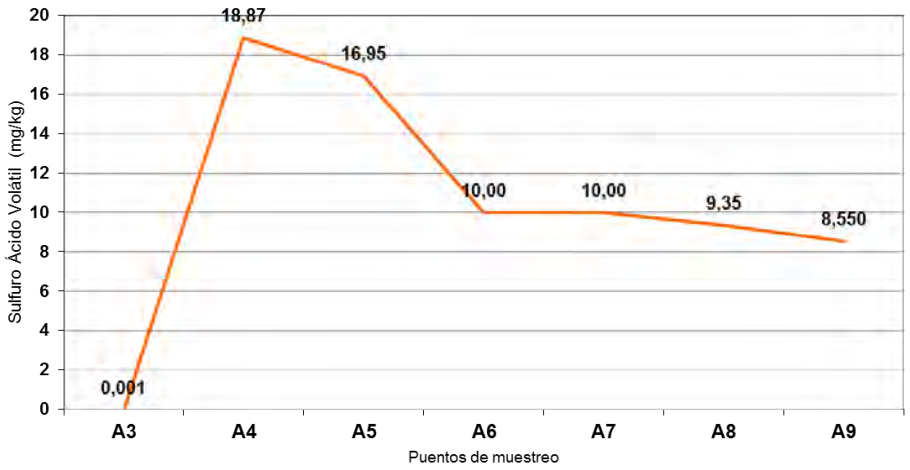


Figure No. 5.182 Volatile Acid Sulphide Behavior
Source: SGS Colombia S.A.S (July 2015)

❖ Chrome

This element can be present in water bodies as Cr III (poorly soluble and very stable) and as Cr VI (less stable, but more soluble, with high mobility between substrates). The concentrations of Chromium in the evaluated marine sediments ranged from 37.8 mg / kg in point A3 to 83.6 mg / kg in point A8, with an average of 71.9 mg / kg. See Figure No. 5.202.

Compared with the Canadian standard (Canadian Sediment Quality Guidelines for the protection of aquatic life), the concentrations in points A4, A5, A6, A7, A8 and A9 are higher than the ISQG standard (52.3 mg / kg), whereas for point A3 the value is lower than this standard. With respect to the PEL index (160 mg / kg) established, it was recorded that all the points are below this limit, so it can be inferred that the concentrations do not interfere in the metabolic activities of aquatic microorganisms.

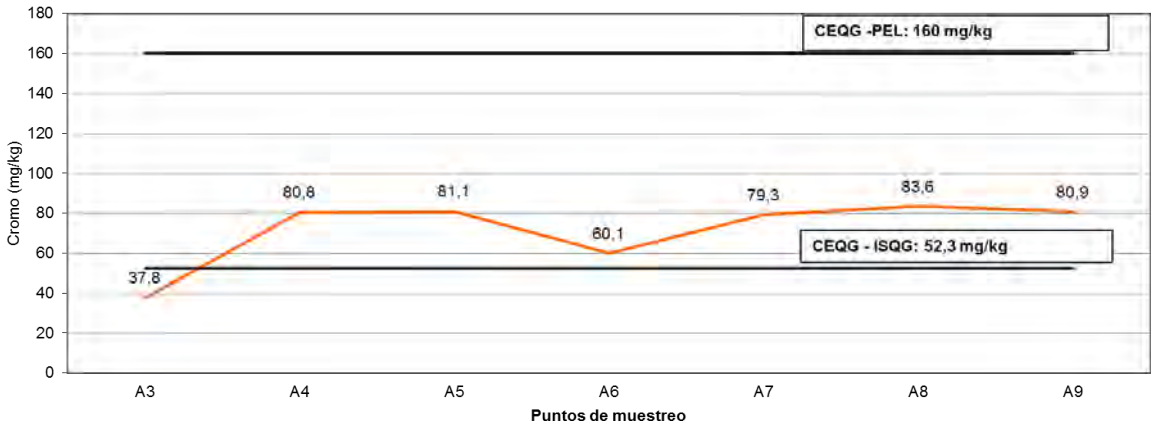


Figure No. 5.183 Chrome behavior
Source: SGS Colombia S.A.S (July 2015)

❖ Zinc

Zinc concentrations were recorded in a range between 104.4 mg / kg (A3) and 218.8 mg / kg (A5). The maximum concentration was registered in point A5, evidencing that for 6 (six) of the 7 (seven) evaluated points, the values exceed the ISQG standard (124 mg / kg), so it can be inferred probable affectation of the conditions biological events as a result of exposure to Zn in sediments.

Otherwise it is presented in the comparison with the PEL standard (271 mg / kg), stipulated in the Canadian guideline (Canadian Sediment Quality Guidelines for the protection of aquatic life), because the concentrations are lower than this value in all the points of sampling. See Figure No. 5.203.

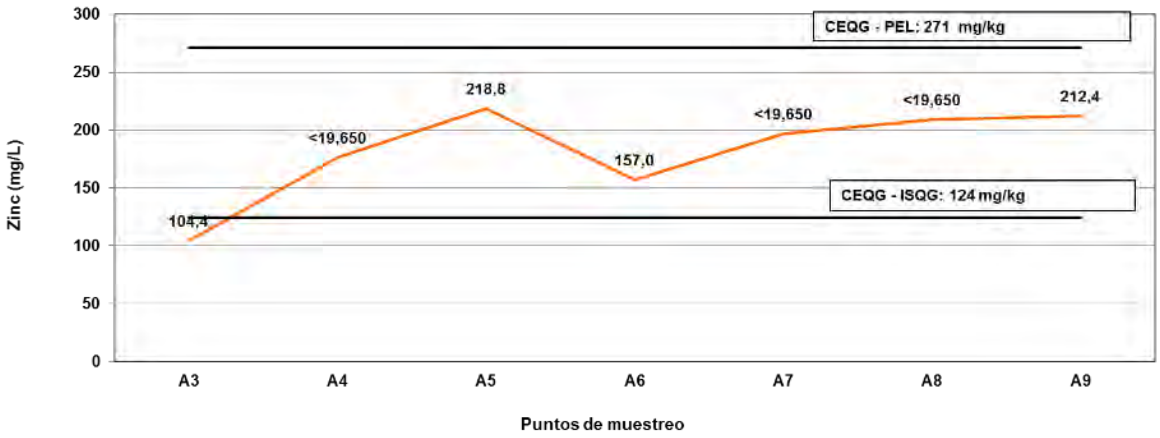


Figure No. 5.184 Zinc Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Mercury

The most contaminating mercurial compounds are represented by the methylated forms, which can be bioaccumulated and transferred through the food chain. The methylated forms of mercury are present in anoxic environments (lacking oxygen) both in the water column, in which it has high solubility, and in the sediments. (ÁLVAREZ, 2005)

The concentrations obtained in all monitored points are lower than the limit of detection of the method of analysis used by the laboratory (0.069 mg / kg) and in turn are lower than the ISQG standard (0.13 mg / kg) and the PEL standard (0 , 70 mg / kg,) stipulated in the Canadian Sediment Quality Guidelines for the protection of aquatic life. See
Figure No. 5.204.

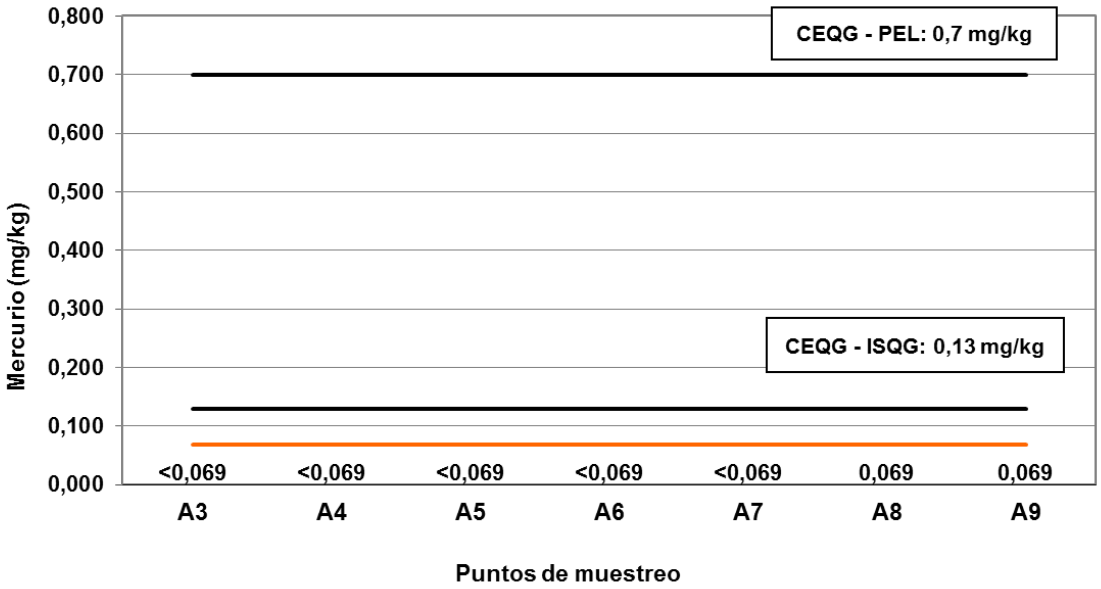


Figure No. 5.185 Comportamiento Mercurio
Source: SGS Colombia S.A.S (July 2015)

❖ Lead

Lead is a metal found naturally in the earth's crust, it is strongly adsorbed in soils and sediments and its main penetration routes are: respiratory and digestive and causes disorders in the biochemical processes of virtually all cells and cells. organism systems.

The concentrations of Lead in the sampling points were registered between 4.1 mg / kg (A1) and 9.1 mg / kg (A9), thus complying with the standards of the Canadian guide, which establishes an ISQG of 30.2 mg / kg and a PEL of 112 mg / kg. See Figure No. 5.205

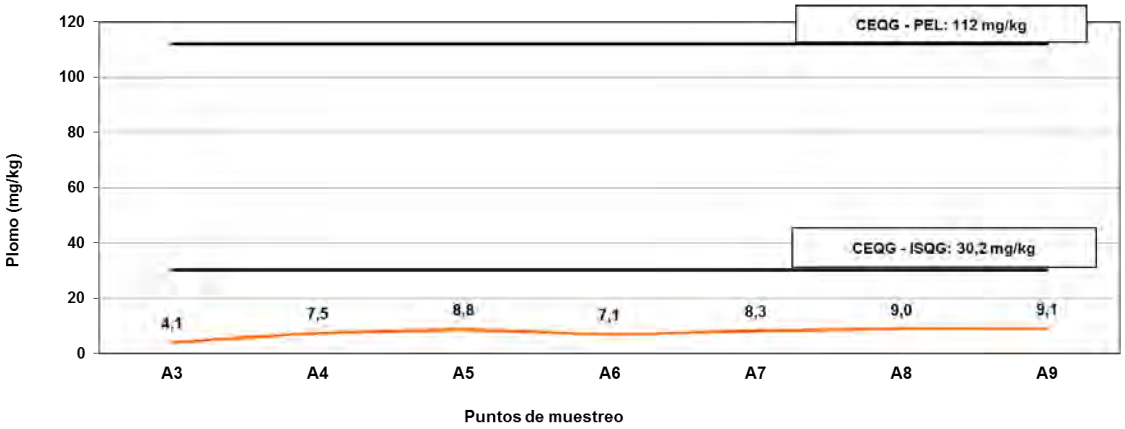


Figure No. 5.186 Lead Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Copper

The concentrations ranged between 33.3 mg / kg (A3) and 91.9 mg / kg (A5). All the sampling points registered are higher than the ISQG standard (18.7 mg / kg), while when compared with the PEL standard (108 mg / kg), all the concentrations are lower than this value, it is affirmed that with respect to this Limit, these concentrations have a low probability of causing adverse biological effects in aquatic life, according to the Canadian guide. See Figure No. 5.206.

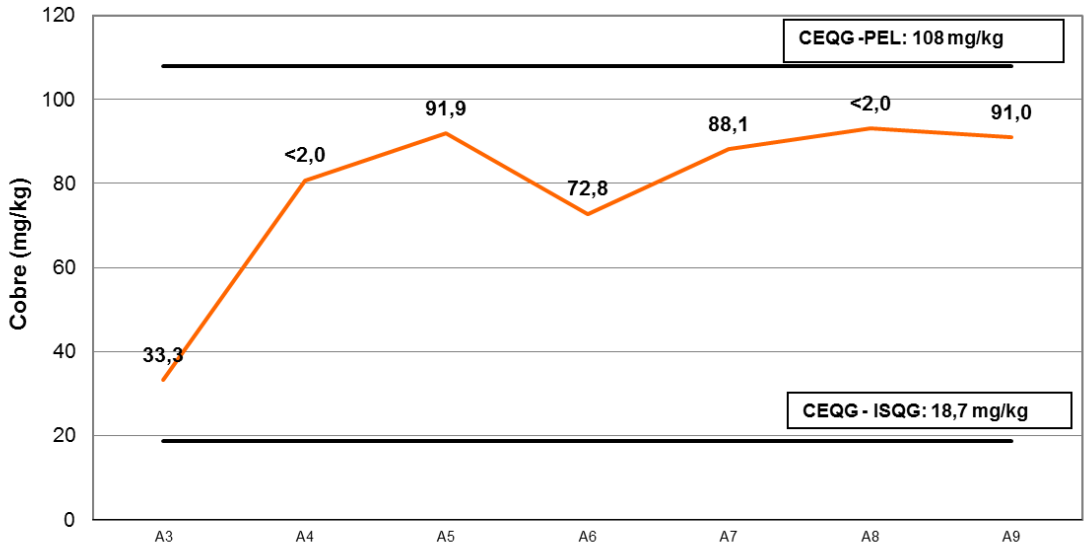


Figure No. 5.187 Copper Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Cadmium

This element occurs in nature in the form of complex oxides, sulphides and zinc carbonates. The mobility of cadmium in aquatic environments is reinforced by low pH, low hardness, low levels of suspended matter, high and low salinity redox potential. In natural water, the bioavailability of cadmium is reduced through the absorption of suspended particles and are biologically responsible for controlling the highest levels of cadmium. In aquatic systems, cadmium is more easily absorbed by organisms directly from water in its free ionic form

UNITED NATIONS ENVIRONMENT PROGRAM - UNEP, 2010.

Cadmium registered in all sampling points units below the limit of detection of the technique used by the laboratory (0.614 mg / kg), stating that the presence of this compound in marine sediments is almost zero and does not affect the physicochemical and biological characteristics of it; About the ISQG standard (0.7 mg / kg) and PEL (4.2 mg / kg), the concentrations are lower and comply fully with the provisions of the Canadian Sediment Quality Guidelines for the protection of aquatic life. See

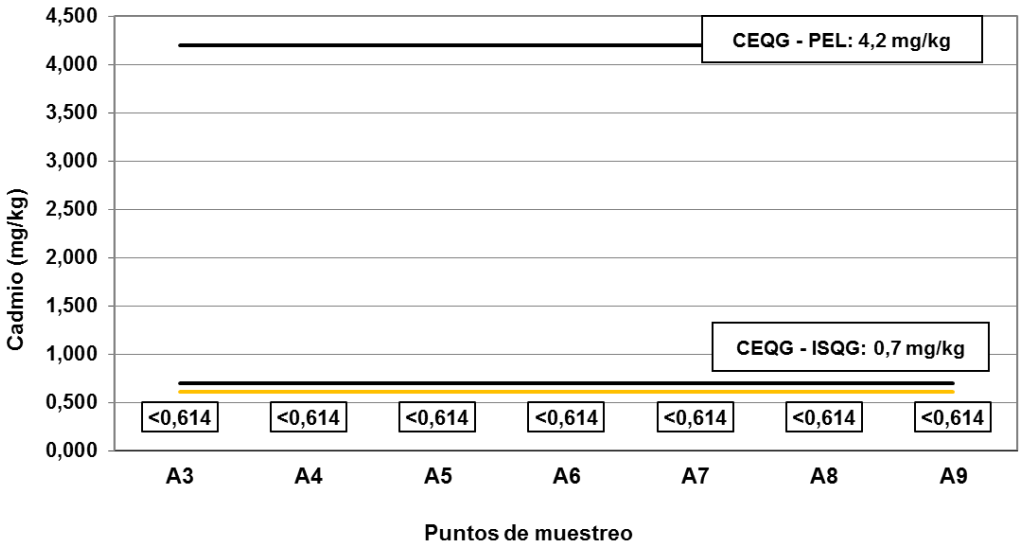


Figure No. 5.188 Chrome Behavior
Source: SGS Colombia S.A.S (July 2015)

❖ Arsenic

For arsenic concentrations between 9.6 mg / kg and 17.4 mg / kg were recorded, at points A3 and A8, respectively. In comparison with the ISQG standard (7.24 mg As / Kg), the values at all points are higher, therefore there are likely to be changes in the dynamics of aquatic organisms due to their bioaccumulation. However, for the PEL standard (41.6 mg As / Kg) it is observed that at all the points the concentrations are lower than this value, for which reason it is possible to infer that the concentrations are not so high that they interfere in the metabolic activities of the aquatic microorganisms. See Figure No. 5.208.

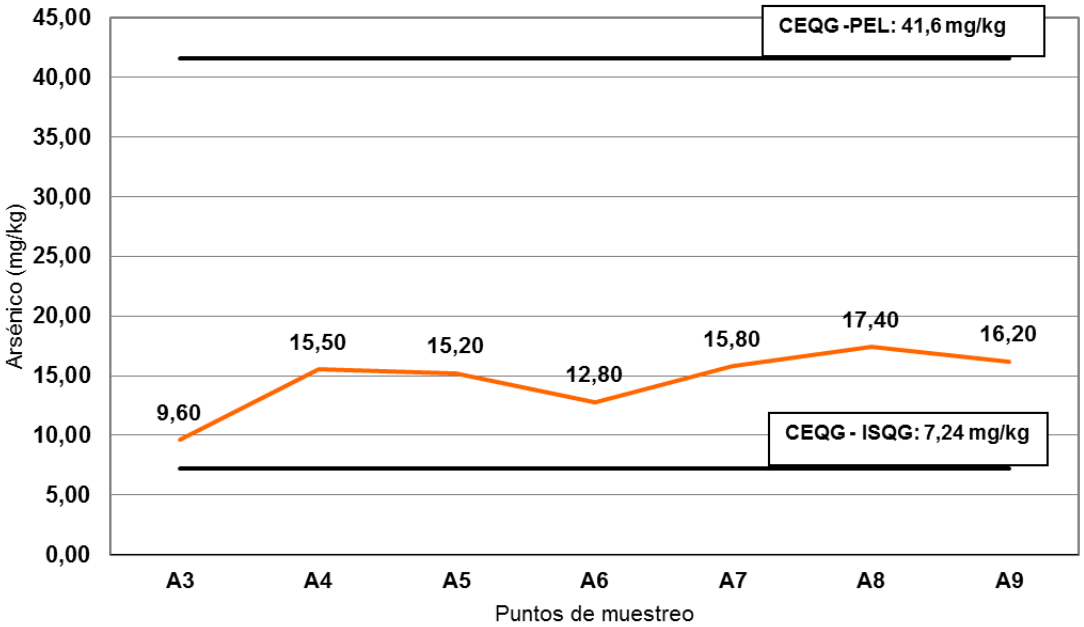


Figure No. 5.189 Arsenic Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Barium

Barium is a common element of nature, but its presence in water is in trace concentrations. The results obtained in the measurement of the Barium allow to establish that the range of concentrations goes from 75.7 mg / Kg (A3) and 136.2 mg / Kg (A6), evidencing a relevant presence of this metal in water. See Figure No. 5.209.

In the Canadian guideline (Canadian Sediment Quality Guidelines for the protection of aquatic life), there are no established limits for this parameter.

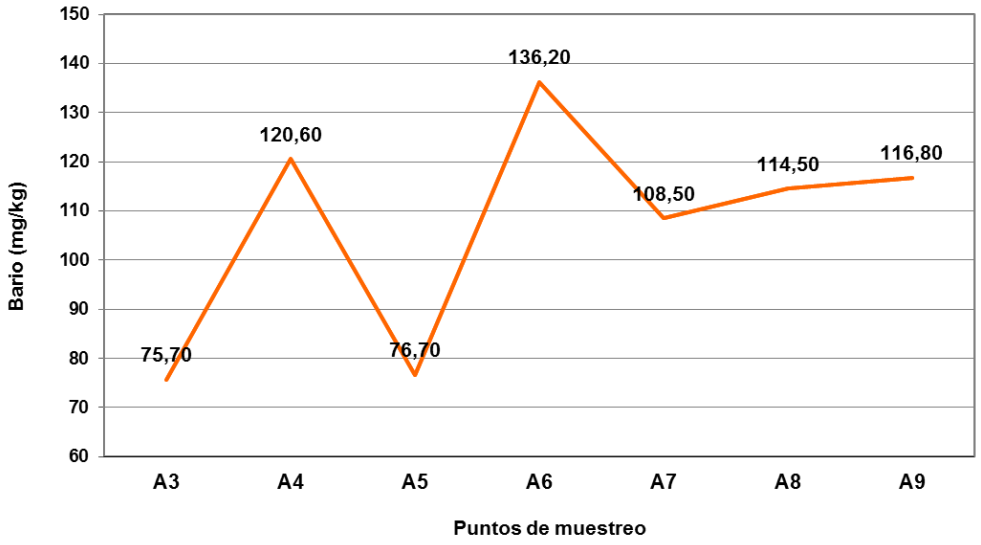


Figure No. 5.190 Barium Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Nickel

Nickel is an essential micronutrient in most organisms, although the concentrations needed are so small that they are rarely limiting for growth and normal cell development. However, when for natural or anthropogenic reasons they are found in water or in the soil at high concentrations they become toxic to organisms.

The analysis of this parameter in the marine sediments of the Urabá Gulf sector, record concentrations that are in a range that goes from 30.5 mg / Kg to 63.7 mg / Kg, however it is not done comparative with standards, since There are no established restrictive limits in the Canadian Sediment Quality Guidelines for the protection of aquatic life. See Figure No. 5.210

JIMENEZ, B. E. Environmental pollution in Mexico, causes, effects and appropriate technology. Ed. Limusa S.A., Mexico, 2005.

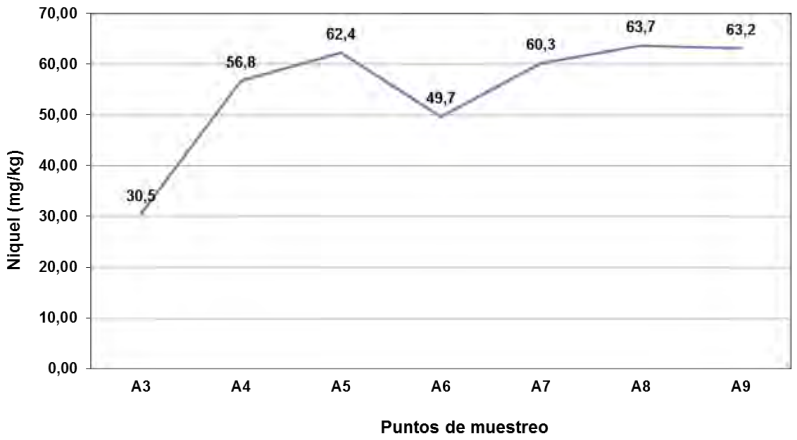


Figure No. 5.191 Nickel Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Selenium

Although it is a non-metallic element, selenium has some of the characteristics of metals, such as its brightness. It also shares properties with sulfur, which is from the same group as the periodic system, and along with that which usually occurs in nature, in the form of metallic selenides, such as copper and lead (zorgite). It is an essential micronutrient for a large number of organisms, animals and bacteria, although it can be very toxic.

This parameter reached concentration values that ranged from 13.2 mg / kg (A3) to 24.8 mg / kg (A9), with little variability in most values, see Figure No. 5.211. In the Canadian guide there are no established limits for this parameter.

Figure No. 5.192 Selenium Behavior

Source: SGS Colombia S.A.S (July 2015)

- **Silver**

Silver is present in nature mainly in the form of very insoluble and stable sulphides and oxides.

According to the results obtained in the measurement of this parameter, it can be evidenced that the concentrations are considerably low for most points, since the values are lower than the limit of detection of the analytical technique (0.0066 mg / Kg), with the exception of points A3 and A5, which reached higher values. The range in which the concentrations are found is <0.0066 mg / Kg and 1.5 mg / Kg. See Figure No. 5.212. The Canadian guide does not set limits for this parameter.

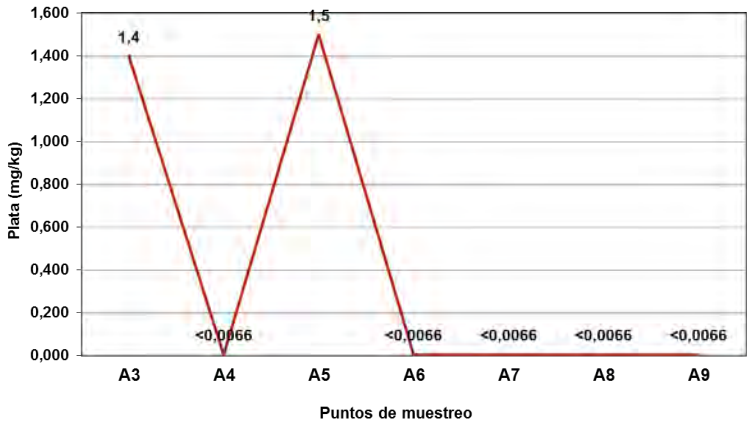


Figure No. 5.193 Silver Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Total phosphorus

The study of nitrogen, phosphorus and the C / N ratio is useful to compare the productivity and decomposition of organic matter and determine the sources of nutrients, their behavior and the relationships between them

The concentrations of total organic phosphorus in the marine sediments registered the limit of detection of the analytical technique (<0.05) for all the points, so it is inferred that the presence of this compound is almost zero.

❖ Total Nitrogen

Total nitrogen registered values ranging from 733 mg / kg (A1) to 2790 mg / kg (A2) with an average of 1851 mg / kg. The maximum concentration was recorded at point A4 and the minimum at point A3. High concentrations can be associated with the accumulation of animal or human organic matter that is sedimented. Additionally, the domestic and industrial discharges generated on the shores of the bay and the runoff that washes floors loaded with nitrogen fertilizers. See Figure No. 5.213.

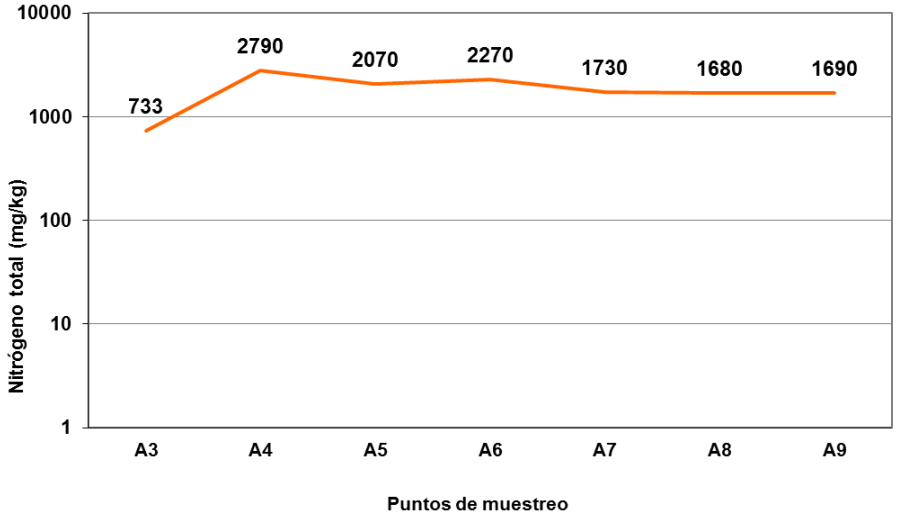


Figure No. 5.194 Total Nitrogen Behavior

Source: SGS Colombia S.A.S (July 2015)

❖ Total Phenols

The reported concentrations in the monitored points are lower than the limit of detection of the analytical technique (<0.01), therefore it can be established that the presence of these compounds in marine sediments from the Bay Colombia sector in the Gulf of Urabá is almost zero and does not generate adverse effects on the physicochemical characteristics.

- Comparison with the international standard

Because the Colombian regulations do not establish limits on the quality of marine sediments, the results obtained were compared with limits established by the Canadian guide "Canadian Sediment Quality Guidelines for the protection of aquatic life". See Table No. 5.77.D

CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT - CCME. Canadian water quality guidelines for the protection of aquatic life: Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving

Numerical Water Quality Objectives. In: Canadian environmental quality guidelines, 1999. [Online] <http://ceqg-rcqe.ccme.ca/en/index.html> [Accessed September 11, 2015]

In the evaluated parameters that have a reference value to compare, the following was found

- The values recorded for copper and arsenic in all sampling stations exceeded the ISQG limit.
- In sampling stations A4, A5, A6, A7, A8 and A9 the chromium and zinc concentrations exceeded the value established for ISQG.

Taking into account that the previously mentioned values exceeded the ISQG limit, but are below the PEL limit, it is expected that in this range the possibility of adverse biological effects will be between 25 and 50%.

On the other hand, the concentrations of cadmium, mercury and lead comply with the limits established by the Canadian guide, that is to say that they are in the minimum effect range within which adverse effects rarely occur (less than 25% of adverse effects under ISQG).

In none of the sampling stations the PEL limit was exceeded for any parameter, therefore no remediation actions are required that require the removal of the contaminant.

Table No. 5.71 Comparison of the results obtained with the norm

PARAMETER	Results of the sampling stations							Canadian Standard Protection of Aquatic Life		Fulfillment
	A3	A4	A5	A6	A7	A8	A9	ISQG	PEL	
Arsenic, mg As / Kg	9,60	15,50	15,20	12,80	15,80	17,40	16,20	7,24	41,6	PEL compliant
Cadmium, mg Cd / kg	<0,614	<0,614	<0,614	<0,614	<0,614	<0,614	<0,614	0,7	4,2	Comply
Copper, mg Cu / kg	33,3	80,8	91,9	72,8	88,1	93,1	91,0	18,7	108	PEL compliant
Chromium, mg Cr / kg	37,8	80,8	81,1	60,1	79,3	83,6	80,9	52,3	160	PEL compliant
Mercury, mg Hg / kg	<0,069	<0,069	<0,069	<0,069	<0,069	<0,069	<0,069	0,13	0,7	Comply
Lead, mg Pb / kg	4,1	7,5	8,8	7,1	8,3	9,0	9,1	30,2	112	Comply
Zinc, mg Zn / kg	104,4	176,5	218,8	157,0	197,1	209,1	212,4	124	271	PEL compliant

Source: *Canadian Sediment Quality Guidelines for the protection of aquatic life*"[219]
ISQG: Intermediate quality standard of sediment
PEL: Level of probable effect

[219] CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT – CCME. Canadian water quality guidelines for the protection of aquatic life: Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving Numerical Water Quality Objectives. In: Canadian environmental quality guidelines, 1999. [En línea] < http://ceqg-rcqe.ccme.ca/en/index.html> [Consultado 11, septiembre, 2015]

• *Quality of deep sea sediments*

In order to know the characteristics of the deep sea sediment in the areas where the deepening dredging activities will be carried out, samples from three (3) drilling were made in Bahía Colombia, located in the Gulf of Urabá, denominated PF8, PF9 and PF10, taking into account that the genesis of these sediments and their formation are mainly due to the same sedimentary dynamics in the whole area, coming from the León River and the Atrato river, reason why it can be affirmed and expected to be very uniform throughout and width of the project area.

- Location of the drilling points for the analysis of depth sediments

The plane coordinates and the location of the points are presented in Table No. 5.78 and Figure No. 5.214, respectively.

Table No. 5.72. Coordinates of the Drilling

Drilling	Plane coordinates	
	Magna Sirgas origin Bogotá	
	East	North
PF-8	703.242,56	1.370.757,58
PF-9	702.766,57	1.370.550,31
PF-10	702.771,47	1.371.303,17

Source EDIFICA COLOMBIA LDTA, PIO S.A.S, 2015[220]

[220] EDIFICA COLOMBIA LDTA, PIO S.A.S, PUERTO ANTIOQUIA. Geotechnical study for the conceptual engineering. Puerto Antioquia. Bogotá D.C, 2015

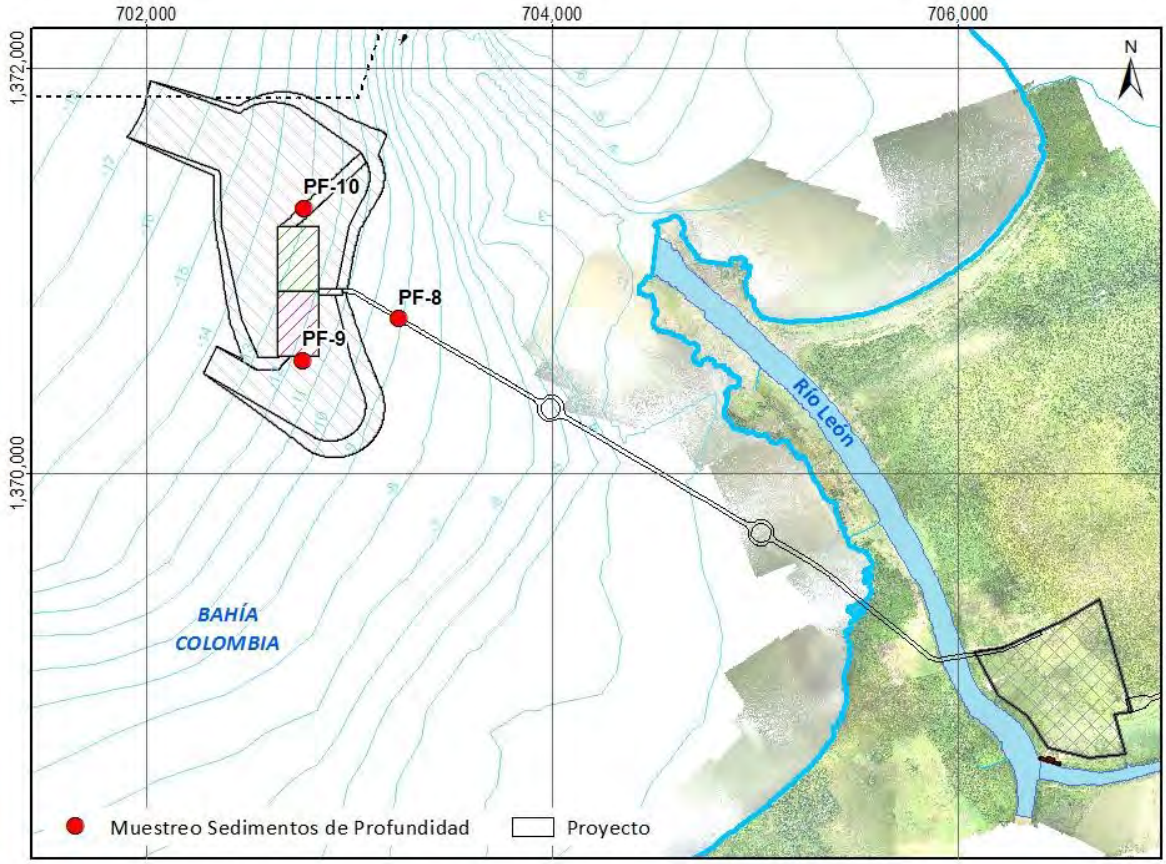


Figure No. 5.195 Location of perforations
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

Drilling PF-08 is located in the area of the viaduct and it will not be necessary to carry out dredging at this point. The other two points (PF-09 and PF-10) correspond to the areas where the deepening dredging would be carried out to adapt the maneuvering areas of the vessels and deep draft vessels that will reach the maritime terminal in the operation stage.

Four (4) samples were taken from each perforation at different depths, so that from the analyzes the different environmental aspects associated with the dredging activity could be inferred and, in turn, anticipate the possible effects on the water column of the deposition of the dredged material in the area assigned as a dump and, thus, propose management measures for the environmental impacts that may arise.

- Results obtained from depth sediment sampling

Table 5.79 presents the results obtained from the analyzes carried out by each laboratory.

Table No. 5.73. Results of analysis of the physicochemical quality of deep sea sediments

Parámetro		PF-8				PF-9				PF-10				CEDEX (España)	
		M1 9,0 - 9,6 m	M2 12,0 - 12,6 m	M3 18,0-18,6 m	M4 20,5- 21,1 m	M1 12,0-12,6 m	M2 15,0-15,6 m	M3 18,0-18,6 m	M4 21,0-21,6 m	M1 13,0-13,6 m	M2 15,75-16,35 m	M3 18,5-19,1 m	M4 21,25-21,50 m	AL1	AL2
Físicos	Temperatura (°C)	23,4	24,3	24,1	24,2	24	23,7	23,6	24,6	24,1	23,9	24	24,1	-	-
	Potencial de Hidrogeno - pH	8,13	8,15	8,34	8,49	7,92	8,34	8,36	6,56	6,28	8,16	8,28	8,35	-	-
Químicos	Grasas y aceites (mg/kg)	525	386	510	514	546	925	891	676	533	1064	432	<200	-	-
	Arsénico (mg/kg)	4,6	4,4	5	4,6	4,6	5	5,6	6	4,2	4,8	3	4,6	80,00	200,00
	Bario (mg/kg)	24,3	25,1	<23,0	<23,0	59,8	<23.0	24,8	52,2	73,1	<23.0	<23.0	<23.0	-	-
	Cadmio (mg/kg)	<7.72	<7.72	<7,72	<7,72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	<7.72	1,00	5,00
	Zinc (mg/kg)	36	32	32	32	38	42	30	32	32	30	32	34	500,00	3000,00
	Cromo (mg/kg)	56	52	66	60	58	66	144	56	48	64	50	60	200,00	1000,00
	Cromo hexavalente (mg/kg)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	-	-
	Cobre (mg/kg)	63,7	73,8	68,1	59,3	61,4	59,5	66,1	46,1	<27.5	66,9	62,3	31,3	100,00	400,00
	Mercurio (mg/kg)	2	<1.8	1,8	<1.8	3,2	<1.8	2,2	<1.8	<1.8	2	<1.8	<1.8	0,60	3,00
	Níquel (mg/kg)	56	60	66	64	60	66	70	56	54	64	46	66	100,00	400,00
	Plomo (mg/kg)	24	20	28	24	20	36	32	32	<20	32	22	26	120,00	600,00
	Selenio (mg/kg)	0,15	0,161	0,147	0,132	0,152	0,136	0,142	0,155	0,153	0,133	0,136	0,141	-	-
	Hidrocarburos Totales %	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	<0.00625	-	-
	Fenoles (mg/kg)	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	-	-
	HAP's (mg/kg)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	-	-
	Carbono Orgánico Total (mg/kg)	22545	35121	31069	28832	19713	24001	24046	24341	15676	23469	15789	22612	-	-
	Fósforo Total (mg/kg)	<1.50	<1.50	3,51	1,68	2,16	5,81	7,95	1,68	2	5,02	6,6	8,79	-	-
	Nitrógeno Total (mg/kg)	1543,13	1480,86	1789	2840,62	1623,97	1309,67	1965,04	1366	1497,27	1390,47	2717,91	4385,62	-	-
	Sulfuro Ácido Volátil (SAV) (%P/P)			9,26		7,52	2,15			6,90	1,00			-	-

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- Analysis and comparison with the regulations

Visual characteristics of the samples

The visual characteristics of the samples varied according to the depth at which they were taken. In a general way you could say:

o Samples of the layer closest to the surface of the seabed (9.0-9.6 m) were made of silty clay with high humidity and plasticity, in addition to having a soft consistency.

o In the samples taken in the following depth (12.0-12.6 m), gray-green clay with some silt, high humidity and soft consistency was present.

o The sediment analysis of the deep layer (18.0-18.6 m) allowed observing a layer of gray clay with some silt, high plasticity and high humidity.

o Finally, the samples from the deepest layer (20.5-21.1 m) could be described as gray-green clay with high plasticity and humidity.

This predominance of clay and muddy beds is related to a large extent by the contributions of sediments from the main rivers of the area, within which there are some streams of the Atrato River and the León River.

Comparison with regulations

Colombia does not have regulations regarding the characteristics of marine sediments produced by dredged material. For this reason, as guide values for the comparison of the results of the physicochemical analyzes, those established by the Center for Studies and Experimentation of Public Works (CEDEX) of Spain will be adopted. This document establishes action levels according to the determined concentration for each parameter evaluated. From these levels, the sediments are classified into four categories.

CHEVILLOT, P., MOLINA, A., GIRALDO, L., & MOLINA, C. (1993). Geological and hydrological study of the Gulf of Urabá. Scientific Bulletin CIOH, (14), 79-89.

The comparison with the Spanish regulations is made for each point independently, indicating the corresponding category for those parameters that have reference values. It is important to clarify that some of the evaluated parameters do not have international reference values, for this reason it is not possible to classify them according to a standard, instead, the related researches published in internationally recognized scientific journals will be used as references.

Table No. 5.80 shows the threshold values associated with each action level for each parameter analyzed.

Table No. 5.74. Values associated with Action Levels 1 and 2 in the Spanish standard

Parameter		CEDEX (Spain)[221]	
		AL1 (mg/kg)	AL2 (mg/kg)
Physical	Temperature	-	-
	Hydrogen Potential – pH	-	-
Químicos	Fats and oils	-	-
	Arsenic	80,00	200,00
	Barium	-	-
	Cadmium	1,00	5,00
	Zinc	500,00	3000,00
	Chrome	200,00	1000,00
	Hexavalent chromium	-	-
	Copper	100,00	400,00
	Mercury	0,60	3,00
	Nickel	100,00	400,00
	Silver	-	-
	Lead	120,00	600,00
	Selenium	-	-
	Total Hydrocarbons	-	-
	Phenols	-	-
	HAP's	-	-
	Total organic carbon	-	-
	Volatile Acid Sulphide	-	-
	Total phosphorus	-	-
	Total Nitrogen	-	-

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

[221] Ibid.

According to the classification made by CEDEX, the following is established:

AL1 and AL2: These are the action levels 1 and 2, which correspond to the limit values used for the classification of the degree of contamination of the dredged material according to the following categories:

o Category I: When the value is less than AL1. Dredged materials from port funds whose chemical and / or biochemical effects on marine ecosystems are insignificant belong to this category.

o Category II: When the value obtained is between AL1 and AL2. In this case there is a moderate concentration of pollutants and discharges of material dredged to the sea should be made taking into account special considerations related to site selection, impact assessment and environmental monitoring programs in the area.

o Category III: When the value of AL2 is exceeded. Dredged materials with a high concentration of contaminants belong to this category, therefore they must be isolated from marine waters or subjected to special treatments prior to disposal in the dumping area.

Within category III we find two subgroups:

• Category IIIa. Within this category are those whose concentration of contaminants exceeds the action level 02 but are below eight (08) times the value of AL2. Corresponds to materials that require soft insulation management techniques such as underwater confinement and discharge into aquatic or terrestrial enclosure.

• Category IIIb are those materials whose concentration of contaminants is greater than eight (08) times the value of AL2. They require hard treatment and storage techniques, such as pouring into enclosures with specific characteristics (impermeable walls, leachate control devices, among others) for the storage of these, the "on line" treatment before performing the dumping at sea and the solidification or inertization for land disposal.

For a better visualization of the comparisons between the results and the Spanish standard, a color will be assigned to each category, as shown in Table No. 5.81.

Table No. 5.75. CEDEX category for dredged material based on the concentration of pollutants

Category I	
Category II	
Category IIIa	
Category IIIb	

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

Based on the above information, we proceed to perform the analysis of the results obtained in each drilling. Below are the concentrations corresponding to the different samples of each point.

❖ Drilling PF8

In Table No. 5.82, the results of all the samples taken in drilling PF8 are compared with the CEDEX standard and classified by color and category according to Table No. 5.81.

Table No. 5.76. Comparison of results in PF8 with the Spanish standard and classification of the result

Parameter		PF-8				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 9,0 - 9,6 m	M2 12,0 - 12,6 m	M3 18,0 - 18,6 m	M4 20,5- 21,1 m	AL1	AL2	
Physiques	Temperature (°C)	23,4	24,3	24,1	24,2	-	-	N/A
	Hydrogen Potential - pH	8,13	8,15	8,34	8,49	-	-	N/A
Chemicals	Fats and oils (mg / kg)	525	386	510	514	-	-	N/A
	Arsenic (mg / kg)	4,6	4,4	5	4,6	80,00	200,00	I
	Barium (mg/kg)	24,3	25,1	<23.0	<23.0	-	-	N/A
	Cadmium (mg/kg)	<7.72	<7.72	<7.72	<7.72	1,00	5,00	N/A
	Zinc (mg/kg)	36	32	32	32	500,00	3000,00	I
	Chrome (mg/kg)	56	52	66	60	200,00	1000,00	I
	Hexavalent chromium (mg / kg)	<0.25	<0.25	<0.25	<0.25	-	-	N/A
	Copper (mg/kg)	63,7	73,8	68,1	59,3	100,00	400,00	I
	Mercury (mg/kg)	2	<1.8	1,8	<1.8	0,60	3,00	II
	Nickle (mg/kg)	56	60	66	64	100,00	400,00	I
	Silver (mg/kg)	<18	<18	<18	<18	-	-	N/A

Parameter		PF-8				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 9,0 - 9,6 m	M2 12,0 - 12,6 m	M3 18,0 - 18,6 m	M4 20,5- 21,1 m	AL1	AL2	
	Lead (mg/kg)	24	20	28	24	120,00	600,00	I
	Selenium (mg/kg)	0,15	0,161	0,147	0,132	-	-	N/A
	Total Hydrocarbons%	<0.00625	<0.00625	<0.00625	<0.00625	-	-	N/A
	Phenols (mg/kg)	<0.35	<0.35	<0.35	<0.35	-	-	N/A
	HAP's (mg/kg)	<0.03	<0.03	<0.03	<0.03	-	-	N/A
	Total Organic Carbon (mg / kg)	22545	35121	31069	28832	-	-	N/A
	Total phosphorus (mg / kg)	<1.50	<1.50	3,51	1,68	-	-	N/A
	Total Nitrogen (mg / kg)	1543,13	1480,86	1789	2840,62	-	-	N/A
	Volatile Acid Sulphide (SAV) (% P / P)			9.26				N/A

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

Arsenic, zinc, chromium, copper, nickel and lead were located well below the limit that defines Action Level 1. On the other hand, mercury concentrations were recorded in the range of 0.6 - 3.0 mg / kg for samples M1 and M3.

According to the results presented in Table No. 5.82, the dredged material of the depths 9.0-9.6 m and 18.0-18.6 m, belongs to category II since the mercury reaches a moderate concentration. For the other pollutants, the concentrations do not reach risk levels for the aquatic ecosystem.

The result of the sample M1 (9.0 - 9.6 m) is of particular interest for the present study, because it is located at a depth to which dredging will be carried out. While the sample M3 (18.0-18.6 m) is only part of the characterization of the area of influence because the dredging will not reach that depth at this point.

Additionally, it should be noted that samples M2 (12.0-12.6m) and M4 (20.5-21.1m) had mercury concentrations below the limit of detection of the analytical technique used by the laboratory, for this reason it was possible to define the classification of the samples according to the CEDEX categories.

- **Drilling PF9**

In Table No. 5.83 the results of all the samples taken at different depths in the PF9 drilling are compared with the CEDEX standard.

Table No. 5.77. Comparison of results in PF9 with the Spanish standard and classification of the result.

Parameter		PF-9				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 12,0-12,6 m	M2 15,0-15,6 m	M3 18,0-18,6 m	M4 21,0-21,6 m	AL1	AL2	
Physiques	Temperature (°C)	24	23,7	23,6	24,6	-	-	N/A
	Hydrogen Potential - pH	7,92	8,34	8,36	6,56	-	-	N/A
Chemicals	Fats and oils (mg / kg)	546	925	891	676	-	-	N/A
	Arsenic (mg / kg)	4,6	5	5,6	6	80,00	200,00	I
	Barium (mg / kg)	59,8	<23.0	24,8	52,2	-	-	N/A
	Cadmium (mg / kg)	<7.72	<7.72	<7.72	<7.72	1,00	5,00	N/A
	Zinc (mg/kg)	38	42	30	32	500,00	3000,00	I
	Chrome (mg/kg)	58	66	144	56	200,00	1000,00	I
	Hexavalent chromium (mg / kg)	<0.25	<0.25	<0.25	<0.25	-	-	N/A
	Copper (mg/kg)	61,4	59,5	66,1	46,1	100,00	400,00	I
	Mercury (mg/kg)	3,2	<1.8	2,2	<1.8	0,60	3,00	IIIa
	Nickle (mg/kg)	60	66	70	56	100,00	400,00	I
	Silver (mg/kg)	<18	<18	<18	<18	-	-	N/A
	Lead (mg/kg)	20	36	32	32	120,00	600,00	I
	Selenium (mg/kg)	0,152	0,136	0,142	0,155	-	-	N/A

Parameter		PF-9				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 12,0-12,6 m	M2 15,0-15,6 m	M3 18,0-18,6 m	M4 21,0-21,6 m	AL1	AL2	
	Total Hydrocarbons%	<0.00625	<0.00625	<0.00625	<0.00625	-	-	N/A
	Phenols (mg/kg)	<0.35	<0.35	<0.35	<0.35	-	-	N/A
	HAP's (mg/kg)	<0.03	<0.03	<0.03	<0.03	-	-	N/A
	Total Organic Carbon (mg / kg)	19713	24001	24046	24341	-	-	N/A
	Total phosphorus (mg / kg)	2,16	5,81	7,95	1,68	-	-	N/A
	Total Nitrogen (mg / kg)	1623,97	1309,67	1965,04	1366	-	-	N/A
	Volatile Acid Sulphide (SAV) (% P / P)	7.52	2.15					

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

As in point PF8, arsenic, zinc, chromium, copper, nickel and lead were located well below the limit defined by Action Level 1. On the other hand, mercury concentrations of sample M1 (depth between 12.0-12.6 m) exceeded by 6% the level of action 02 since the norm establishes a limit of 3 mg / kg and in the sample 3.2 mg / kg was found, being very close to the threshold, and it can be observed in the sample of the following depth M2, that the concentration of mercury is less than 1.8 mg / kg of Hg, establishing us in Action Level 02, so we can think that it is not an area with a high degree of mercury concentrations since it only exceeds the action level 02 in a very low percentage; close to the margin of error of the same test. On the other hand, at a greater depth in the M3 sample (depth between 18.0-18.6 m) they were in the range between 0.6-3.0 mg / kg Hg, thus confirming the previously analyzed.

Therefore, according to the results presented in Table No. 5.83, the material to be dredged from sample M1 (depth between 12 - 12.6 m) belongs to category IIIa and the material from samples M2 and M3 (depth between 15 -15.6 and 18 - 18.6 m respectively) belong to category II; said material will not be dredged. For the other pollutants, the concentrations do not reach risk levels for the aquatic ecosystem.

On the other hand, it is important to clarify that samples M2 (depth between 15.0-15.6m) and M4 (depth between 21.0-21.6m) showed mercury concentrations below the limit of detection of the analytical technique used by the laboratory, for this reason it is not possible to define the classification of the samples according to the CEDEX categories.

❖ Drilling PF10

In Table No. 5.84, the results of all the samples taken for different depths in the PF10 drilling are compared with the CEDEX standard.

Table No. 5.78. Comparison of results in PF10 with the Spanish standard and classification of the result.

Parameter		PF-10				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 13,0-13,6 m	M2 15,75-16,35 m	M3 18,5-19,1 m	M4 21,25-21,50 m	AL1	AL2	
Physiques	Temperature (°C)	24,1	23,9	24	24,1	-	-	N/A
	Hydrogen Potential - pH	6,28	8,16	8,28	8,35	-	-	N/A
Chemicals	Fats and oils (mg / kg)	533	1064	432	<200	-	-	N/A
	Arsenic (mg/kg)	4,2	4,8	3	4,6	80,00	200,00	I
	Barium (mg/kg)	73,1	<23.0	<23.0	<23.0	-	-	N/A
	Cadmium (mg/kg)	<7.72	<7.72	<7.72	<7.72	1,00	5,00	N/A
	Zinc (mg/kg)	32	30	32	34	500,00	3000,00	I
	Chrome (mg/kg)	48	64	50	60	200,00	1000,00	I
	Hexavalent chromium (mg / kg)	<0.25	<0.25	<0.25	<0.25	-	-	N/A
	Copper (mg/kg)	<27.5	66,9	62,3	31,3	100,00	400,00	I
	Mercury (mg/kg)	<1.8	2	<1.8	<1.8	0,60	3,00	II
	Nickle (mg/kg)	54	64	46	66	100,00	400,00	I
	Silver (mg/kg)	<18	<18	<18	<18	-	-	N/A
	Lead (mg/kg)	<20	32	22	26	120,00	600,00	I
	Selenium (mg/kg)	0,153	0,133	0,136	0,141	-	-	N/A
	Total Hydrocarbons%	<0.00625	<0.00625	<0.00625	<0.00625	-	-	N/A
	Phenols (mg/kg)	<0.35	<0.35	<0.35	<0.35	-	-	N/A
	HAP's (mg/kg)	<0.03	<0.03	<0.03	<0.03	-	-	N/A

Parameter		PF-10				CEDEX (Spain)		Classification of the result with the CEDEX Category
		M1 13,0-13,6 m	M2 15,75-16,35 m	M3 18,5-19,1 m	M4 21,25-21,50 m	AL1	AL2	
	Total Organic Carbon (mg / kg)	15676	23469	15789	22612	-	-	N/A
	Total phosphorus (mg / kg)	2	5,02	6,6	8,79	-	-	N/A
	Total Nitrogen (mg / kg)	1497,27	1390,47	2717,91	4385,62	-	-	N/A
	Volatile Acid Sulphide (SAV) (% P / P)	6,9	1,00					

Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

In drilling PF10 the trend of the previous points is maintained, where most of the parameters comply with what is established by the Spanish standard: arsenic, zinc, chromium, copper, nickel and lead, were located well below the limit that defines the Action level 1. On the other hand, the mercury concentrations of sample M2 (depth between 15.75-16.35 m) were in the range between 0.6-3.0 mg / kg of Hg.

Therefore, according to the results presented in Table No. 5.84, the dredged material of sample M2 belongs to category II, given that the mercury reaches a moderate concentration. For the other pollutants, the concentrations do not reach risk levels for the aquatic ecosystem.

On the other hand, it is important to clarify that the samples M1 (13.0-13.6 m), M3 (18.5-19.1 m) and M4 (21.25-21.50 m) presented concentrations of mercury below the limit of detection of the analytical technique used by the laboratory, for this reason it is not possible to define the classification of the samples according to the CEDEX categories.

Analysis of results

Next, the results obtained in the samples of deep sea sediments, extracted in three (3) points located in Bahía Colombia - Golfo de Urabá, are analyzed.

- **Physical parameters temperature and pH**

The temperature and pH of the sediments presented values within the typical ranges in marine ecosystems. The average temperature of all the samples taken at points PF8, PF9 and PF10 was 24 ° C, without significant variations between the samples taken at the same point. See Figure No. 5.215.

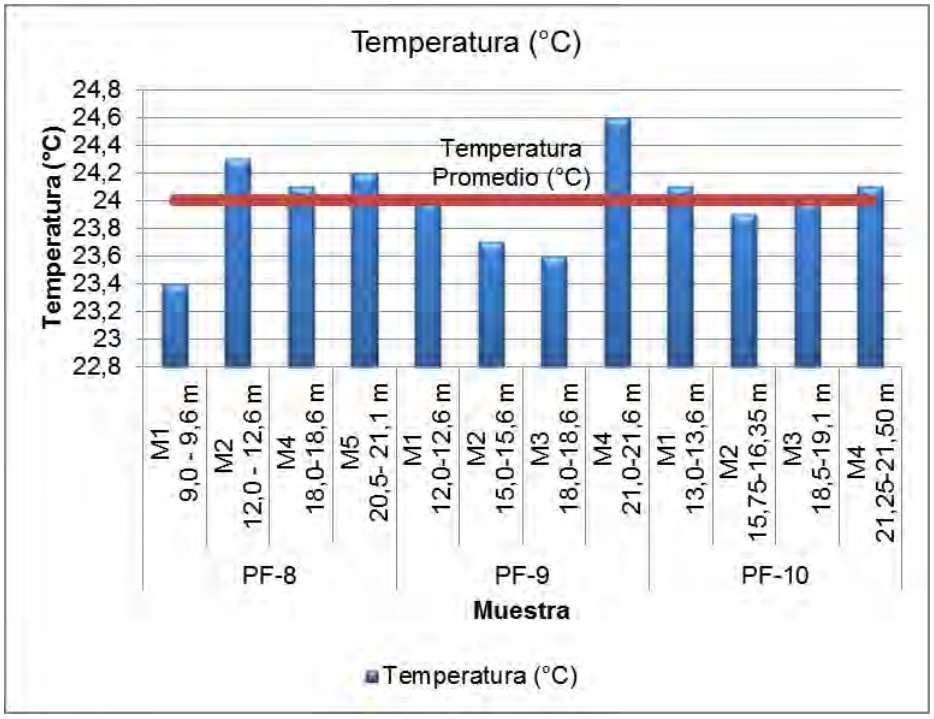


Figure No. 5.196. Temperature behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

With regards to pH, averaging the results obtained at each point, the pH at point PF8 was 8.3, at point PF9 it was 7.9 and at point PF10 it was 7.8 so that consider slightly alkaline sediments. See Figure No. 5.216

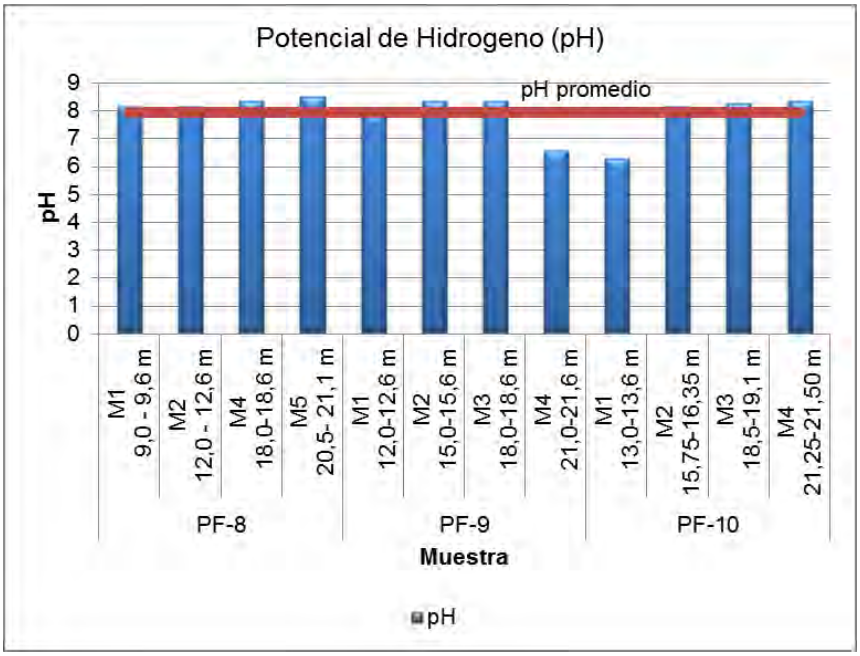


Figure No. 5.197. PH behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- **Chemical parameters: organic compounds and trace elements (inorganic)**

Within all the elements and compounds characterized, only for some trace elements there was reference information (international) from which the quality of the marine sediment could be established. Thus, for example, barium is an element that does not have information on the environmental effects it can have on marine sediments. Similarly, it occurs with Selenium, whose studies focus on the mobilization and effects of this element in the water and soil matrix, excluding sediments.

On the other hand, elements like cadmium, zinc, chromium, copper, mercury, nickel and lead have been extensively studied due to their environmental importance, the effects produced on aquatic biota, the potential for bioaccumulation and their persistence. The results obtained for these elements were compared with the values of marine sediment quality developed in Spain, applicable mainly for dredged material.

MINISTRY OF PUBLIC WORKS TRANSPORTATION AND THE ENVIRONMENT. (1994). Recommendations for the management of dredged material in Spanish ports. Madrid Spain

It is important to characterize these ions since, although some are considered as micronutrients and are essential for organisms (Na, K, Ca, Cu, Fe, Mn and Zn), others are considered as toxic ions and of no biological use (Pb , Cd, Hg and Ag).

- **Arsenic (As)**

The presence in these concentrations is mainly due to contributions of natural origin due to the weathering of the parent rock. On the other hand, there may be small contributions derived from agricultural activity in the area.

When comparing the results with the reference values of the Spanish regulations (see Figure No. 5.217) it can be seen that all the results are below Action Level 01 (AL-01), that is, in relation to arsenic, the sediments belong to Category I and there is no significant effect on the ecosystem.

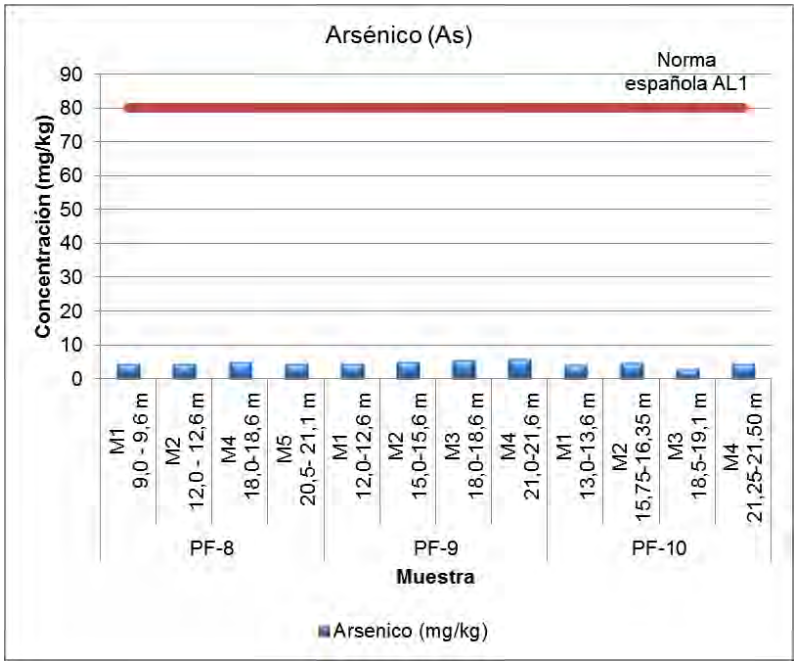


Figure No. 5.198. Behavior of Arsenic
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- **Cadmium (Cd)**

The main sources of this element are the washing of agricultural soils and the contributions of mining, activities that constitute the productive base of the Urabá region, mainly with the exploitation of woods of natural forest, the extraction of gold and platinum and crops of rice.

According to Spanish regulations, for the sediment to be classified in Category I, the concentration of this element should be less than 1.00 mg / kg, and to be classified as Category II, the concentration should be between 1.00 mg / kg and 5.00 mg / kg. If this last value is exceeded, it would be classified as category III material.

However, given that the minimum detection limit of the analytical technique used by the laboratory was 7.72 mg / kg, it is not possible to compare the results with the mentioned study.

- **Copper (Cu)**

Copper is a metal that occurs naturally in rocks, soil, water and air. And it is essential for the metabolism of plants, animals and humans. Some specific sources of this metal are wind, volcanic particles, forest fires and biogenic processes. It is also possible that the copper is related to the discharges of sludge treatment plants.

When comparing the results with the reference values of the Spanish regulations (Figure No. 5.218) it can be seen that all the results are below Action Level 01 (AL-01), that is, in relation to copper, the Sediments belong to Category I and there is no negative impact on the ecosystem.

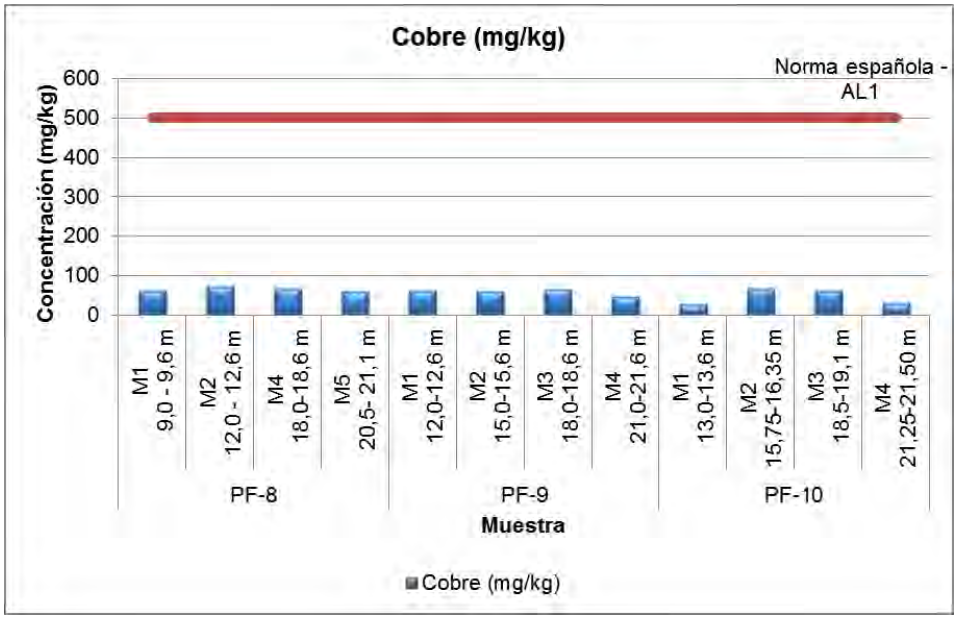


Figure No. 5.199. Copper Behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

❖ Chrome (Cr)

The presence of this element is usually manifested by natural causes and by contributions of agricultural activity, similar to what occurs with arsenic.

Making the comparison with Spanish regulations, chromium is another of the metals that is below the limit of Action Level 1 (AL1), which means that the concentration in the material that would be dredged would not represent any inference for this element about the aquatic environment. See Figure No. 5.219.

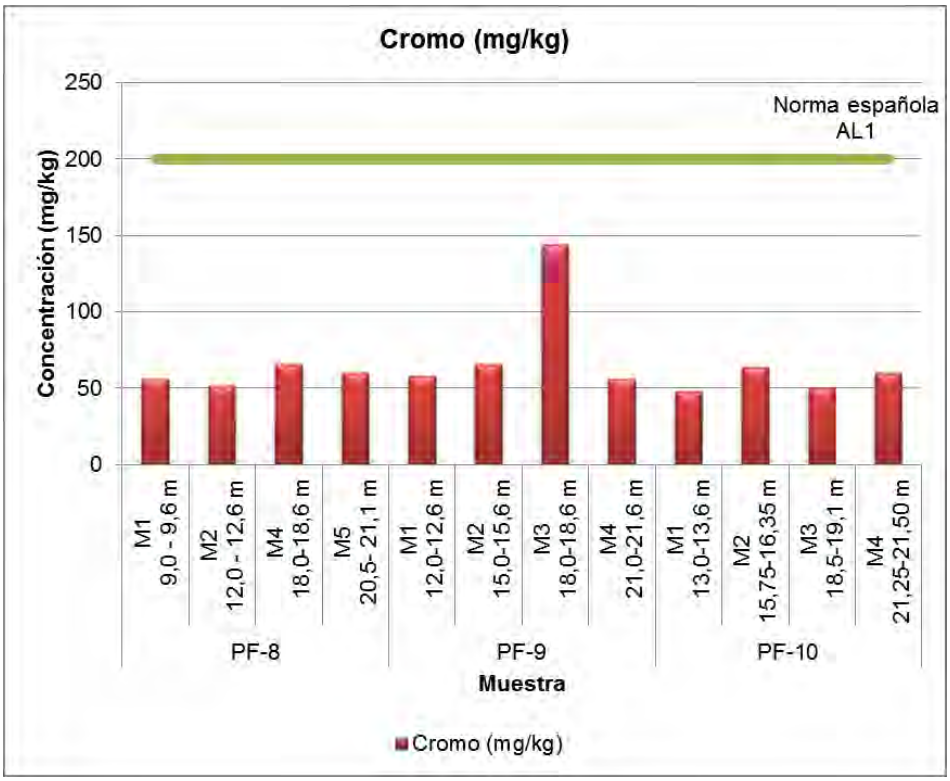


Figure No. 5.200. Chrome behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

❖ Mercury (Hg)

The most common chemical form of this element in the environment is Methylmercury, produced mainly by the microbiological activity of organisms present in water and soil. The production of this one increases with the presence of metallic mercury.

The main problem of this metal in the environment, in addition to toxicity, is persistence and bioaccumulation. That is why after many years the concentrations can remain high, even without a source that generates new contributions. In addition, if it is methylmercury, which is the most toxic form, bioaccumulation and persistence are facilitated in the trophic chain due to its high solubility in lipids and the ease of traversing membranes in the body.

On the other hand, sediments are the main mercury receptor in aquatic ecosystems because their organic forms tend to adsorb onto suspended material that tends to settle and accumulate in the bed over the years. As Cogua puts it "Aquatic sediment analyzes have a special role in the assessment of mercury contamination, because their results can reveal the current status of environmental deposition."

After comparing the results obtained by the laboratory with Spanish regulations (See Figure No. 5.220), three conditions could be observed:

a) In seven (07) of the samples analyzed (samples M2 and M4 of point PF8, samples M2 and M4 of point PF9, and samples M1, M3 and M4 of point PF10), the concentration was lower than the limit of detection of the analytical technique used.
b) Four (04) of the samples (samples M1 and M3 of point PF8, sample M3 of point PF9, and sample M2 of point PF10) recorded concentrations between 0.6 and 3.0 mg / kg. Therefore, according to the Spanish regulations, the sediment is classified as Category II and the concentration of the pollutant is moderate, which is why aspects such as the selection of the site, the evaluation of the and the elaboration of a monitoring and surveillance plan, to be able to carry out the dredging of the dredged material
c) Only one of the samples (sample M1 of the PF9 point) exceeded by 6% the Action Level 2 (AL2) established by the Spanish standard. For this reason, Category III, subcategory IIIa, is assigned to the dredging material of point PF9, being very demanding since as mentioned above we are very close to the threshold of action category 2

Taking into account the above, the material of the first layer to be dredged, should be deposited in the central area of the dump, to be later covered with material from the following dredging layers whose concentrations of mercury are below the action level. 2; and in this way avoid a possible alteration of the ecosystem around the dumping area.

The presence of mercury could be associated with mining activities developed in the Atrato river basin, corroborating the information presented by the Antioquia Governorate in the document: "El Urabá Antioqueño: a sea of opportunities and potential", where it is stated that It is one of the six critical areas of pollution in the Colombian Caribbean due to contamination by domestic wastewater, dissolved hydrocarbon residues and organochlorinated pesticides.

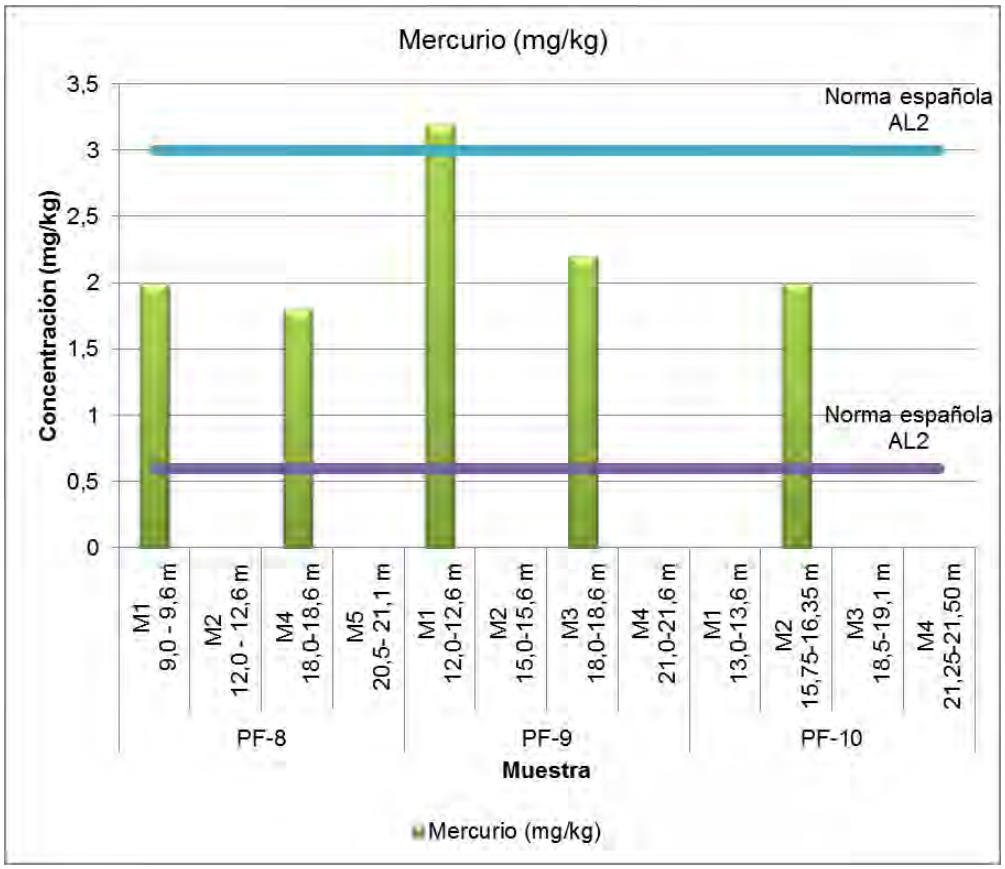


Figure No. 5.201. Mercury behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- **Nickle (Ni)**

It is a metallic element widely distributed in the earth's crust that is used for diversity of applications at the industrial level, which is why it is easy to produce contamination with this element due to the improper handling of solid waste and dumping. Despite this, the analyzes carried out in Bahía Colombia showed concentrations below Action Level 1 (AL1) defined by Spanish regulations (Figure No. 5.221). That is, the

material that will be dredged can be included in category I in relation to nickel and therefore the concentration does not represent any negative impact for aquatic biota.

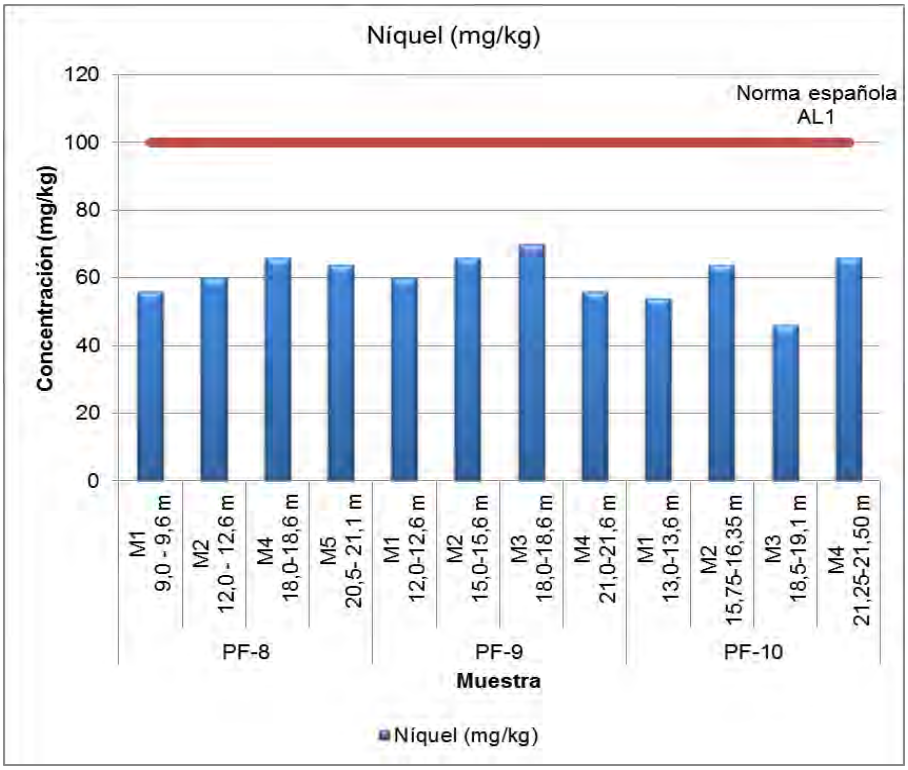


Figure No. 5.202. Nickel Behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- **Silver (Ag):**

Research has been carried out demonstrating the toxicity of bacteria, phytoplankton and marine invertebrates, as well as the strong bioaccumulation produced in these organisms. However, the behavior and distribution of this element in the water column remains quite unknown due to the difficulty in determining the small concentrations of the dissolved element.

In 2012, based on research conducted under the Southern California Coastal Water Research Project, guideline values were defined to classify sediment toxicity according to silver analyzes. There was defined a value of Effect range-medium (ERM) of 3.5 mg / kg, that is, from this concentration it is very likely that negative effects occur on the marine biota However, given that the minimum detection limit of

the analytical technique used by the laboratory is below 18 mg / kg it is not possible to compare the results with the mentioned study.

[1] BAY, S. M., RITTER, K. J., VIDAL-DORSCH, D. E., & FIELD, L. J. (2012). Comparison of national and regional sediment quality guidelines for classifying sediment toxicity in california. Integrated Environmental Assessment and Management, 8(4), 597–609. http://doi.org/10.1002/ieam.1330

❖ Lead (Pb)

It is a metal found naturally in soils, plants and water at trace levels. It is an important element if one takes into account the toxicity for living beings. The results obtained show that the registered concentrations are at levels that do not represent any danger to the organisms of the marine ecosystems of the Gulf of Urabá. See Figure No. 5.222.

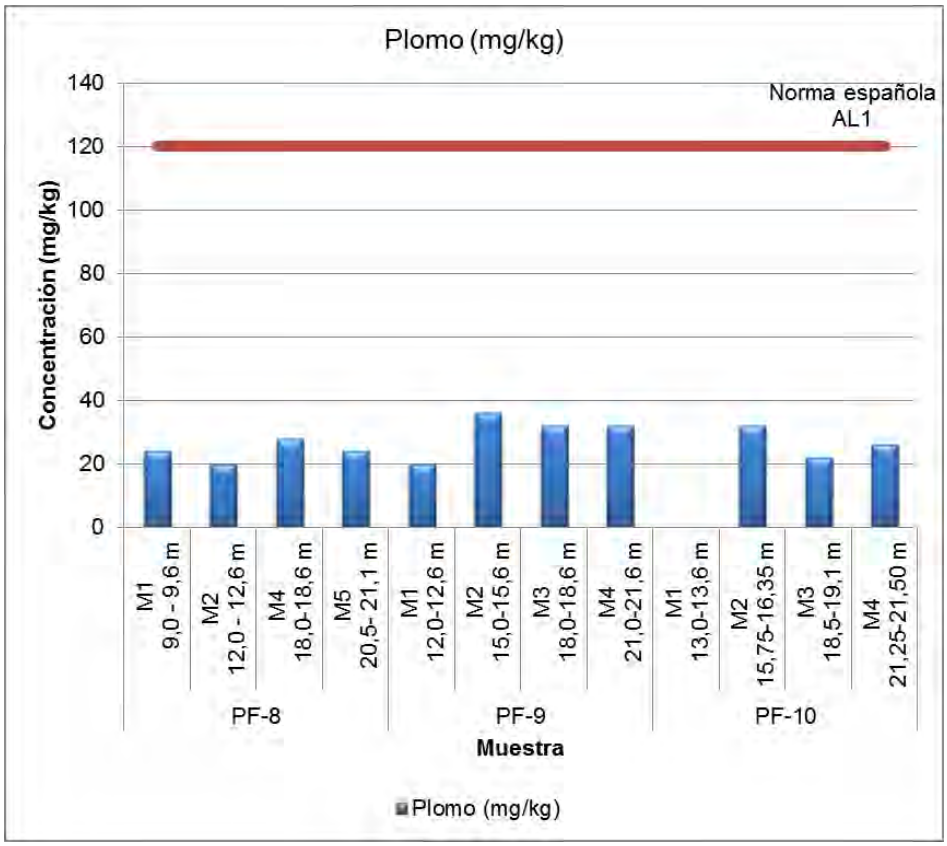


Figure No. 5.203. Lead Comparison
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

❖ Volatile Acid Sulfide (AVS)

Defined as the reactive fraction of solid phase sulfide that can be extracted with cold hydrochloric acid, it is one of the components involved in speciation and the environmental risks of heavy metals contained in sediments. On the other hand, there are the Simultaneously Extracted Metals (SEM), which are those extracted during the same analytical process of the AVS and are mainly made up of Cd, Cu, Ni, Pb and Zn.

Several studies have suggested that the relationship between the molar concentration of the AVS ([AVS], µmol / g) and that of the SEM ([SEM], µmol / g) is a possible indicator of the toxicity of metals in sediments. anaerobic Because the sulfur ions can be combined with the metal ions in their divalent form converting them into insoluble species. However, this has a bias because the other components of the sediment, such as organic matter, can be combined with metal ions, reducing their bioavailability and toxicity. This is established by studies that suggest a correlation between the presence of metals in the sediments, the granulometry of the soil and the concentration of total organic carbon (TOC).

The results of the laboratory show that there is a high concentration of SAV and COT (See Figure No. 5.223 and Figure No. 5.224) with respect to trace metals. Based on this, it could be inferred that the metal ions present will not be transformed in their bioavailable forms, meaning that the probability of toxic substances forming in the sediments is considerably low.

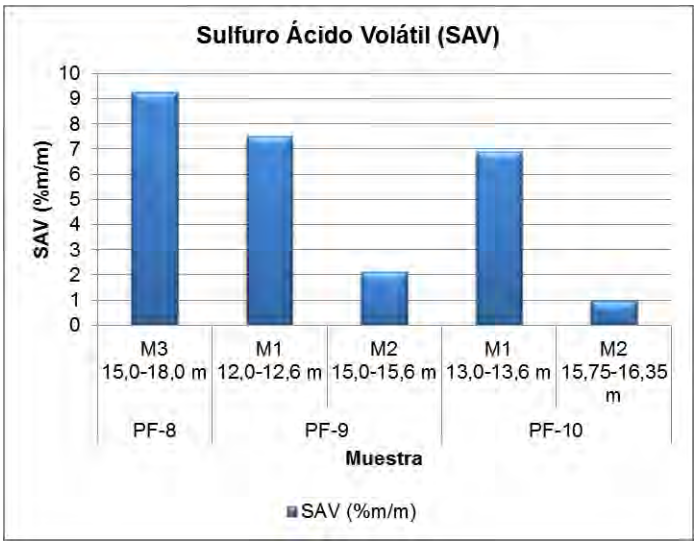


Figure No. 5.204. Volatile Acid Sulfide Behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

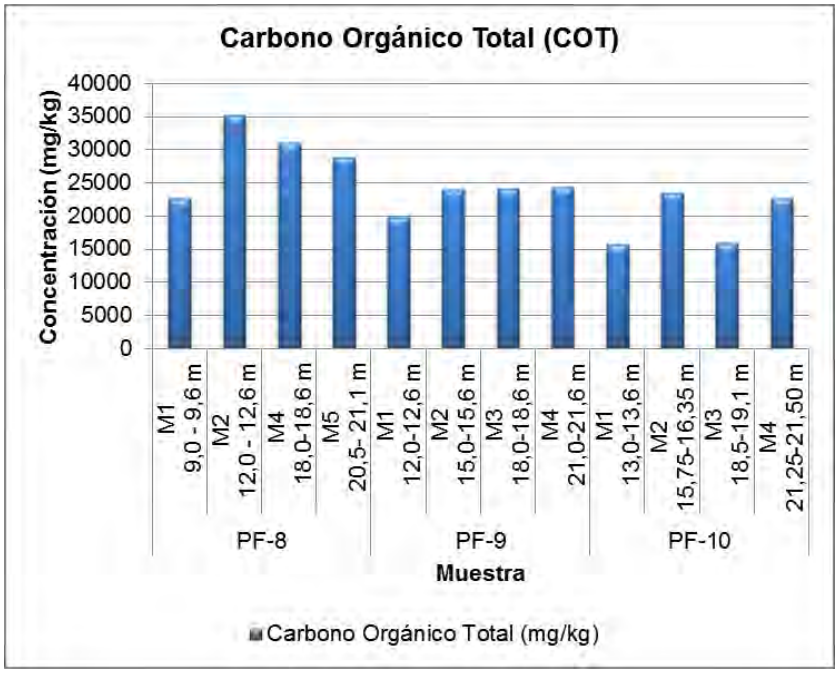


Figure No. 5.205. Total Organic Carbon Behavior (TOC)
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

- **Zinc (Zn)**

This ion is common in the water of both rivers and the sea, being in higher concentrations for the former. It is also a fundamental element in the metabolism of all living beings since it is constituent of more 200 metalloenzymes and other metabolic compounds.

In its elemental state does not constitute any risk for aquatic biota, however, some derivatives such as arsenate and zinc cyanide, as the ingestion of excessive amounts can be toxic to any organism.

When comparing the results with the reference values of the Spanish regulations (see Figure No. 5.225) it can be seen that all the results are well below Action Level 01 (AL-01), that is, in relation to this element, the sediments belong to Category I and there is no significant effect on the ecosystem.

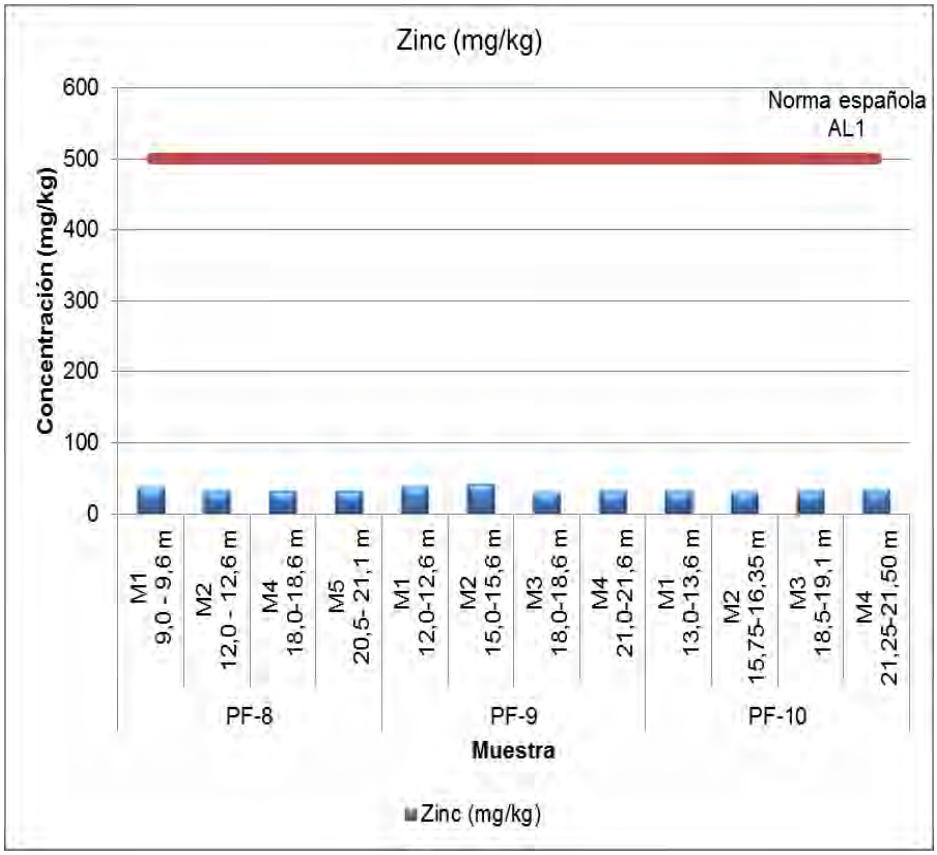


Figure No. 5.206. Zinc Behavior
Source: Aqua & Terra Consultores Asociados S.A.S. (2015)

5.1.10 Geotechnics

The studies and analysis of the geotechnical information made by Edifica Colombia (2015)[222] for the area of intervention are presented in Annex 5.1.2 Geotechnical Final Report. Studies were carried out for the conceptual design stage under this project, which included, among others, 10 boreholes between 70 m and 100 m depth (seven (7) in water and three (3) on ground) and four (4) piezocons CPTu (two (2) in water

[222] EDIFICA COLOMBIA LDTA, PIO S.A.S, PUERTO ANTIOQUIA. Geotechnical study for conceptual engineering. Port Terminal Puerto Antioquia. Bogotá D.C, 2015.

and two (2) in ground). The location of the exploration points is presented in Figure No. 5.226 and in the MOD_LA_PTO_ANT_27_Geotecnia map.

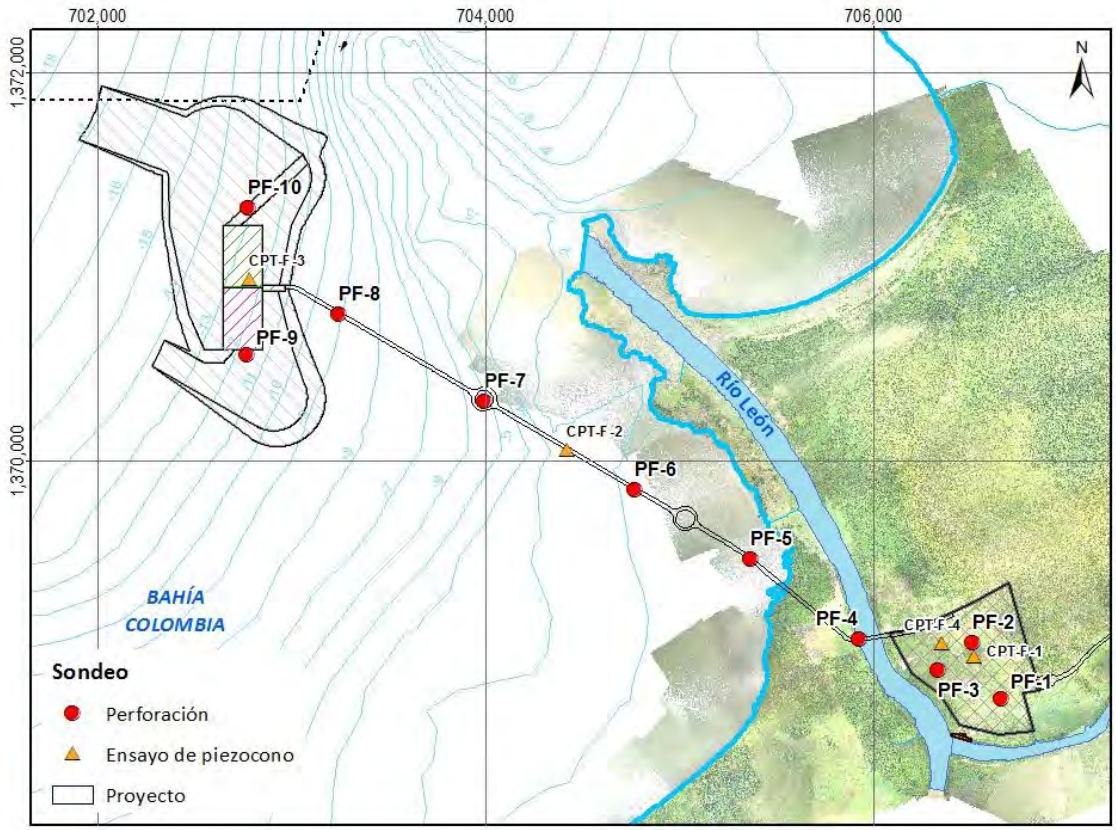


Figure No. 5.226 Location of geotechnical exploration points
Source: Aqua & Terra Consultores Asociados S.A.S, 2015 with information from EDIFICA, 2015

A total of 14 boreholes were drilled with mechanical equipment performing data collection with CPT (Cone Penetration Test), SPT (Standard Penetration Test), VST (Vane Shear Test) equipment, also in the drilling that was carried out, altered and unaltered samples were taken. The samples obtained in the exploration fulfilled a program of soil laboratory tests for its visual and geomechanical description.

The drilling reached depths between 70 and 100 meters, counted from the mean sea level. Table No. 5.85 shows the depths reached in the exploration, as well as the thickness of the water sheet at each point of control or drilling.

Table No. 5.85 Location and depths of the drilling points

POINT	WATER COLUMN (m)	SOIL COLUMN (m)	DRILLING DEPTH (m)
PF-1	0.0	70.0	70.0
PF-2	0.0	80.0	80.0
PF-3	0.0	80.0	80.0
PF-4	2.0	78.0	80.5
PF-5	1.0	80.0	81.0
PF-6	1.1	79,4	80.5
PF-7	6.0	74.0	80.0
PF-8	9.0	71.5	80.5
PF-9	12.0	69.0	81.0
PF-10	13.0	87.0	100.0
CPT-F1	0.0	35.0	35.0
CPT-F2	2.0	42.0	40.0
CPT-F3	10.0	43.0	53.0
CPT-F4	0.0	38.0	38.0

Source: Prepared by Aqua & Terra Consultores Asociados S.A.S, 2015 with information from Edifica Colombia Ltda, 2015

The following laboratory tests were carried out on the samples recovered in the drillings:

- Natural humidity
- Consistency limits
- Unit weight
- Unconfined compression
- Granulometry and sieving
- Consolidation
- Direct cuts
- Triaxial
- Resonant Column
- Bender Element

The drilling information generated by Edifica Colombia Ltda is recorded in Annex 5.1.2, in which the type of sampling carried out, the tests and field data taken is registered.

- *Material's Geotechnical Zoning*

With the results of standard penetration tests, penetration tests with Dutch cone, field vane cutting tests, unconfined compressions, direct cutting and triaxial tests on the recovered samples, geotechnical zoning was carried out based on resistant characteristics of the material of the subsoil following the following premises presented in Table No. 5.86:

Table No. 5.86 Geotechnical classification of subsoil material according to drilling resistance (mainly granular soils) and undrained shear resistance (mainly cohesive soils)

Nomenclature	Geotechnical classification of the material (consistency / relative density)	Resistance to penetration Standard (Nspt)	Undrained shear strength (Su) (Kg / cm2)	Color code
1	**(Very soft / very loose)** fluvial-marine deposit mainly mudstone, with silty clay material, and sand intercalations. High Humidity and plasticity	Nspt< two blows	Su < 0,25	
2	**(Soft / very loose)** fluvial-marine deposit, with silty clay material, and sand intercalations. High Humidity and plasticity	2 < Nspt < 4 blows	0,25 < Su < 0,50	
2	**(Little compact / loose)** Silty clay with high plasticity, medium to low humidity	4 < Nspt < 8 blows	0.50 < Su < 1.00	
3	**(Compact / medium density)** Slime-sandy clay, medium plasticity, medium to low humidity	8 < Nspt < 15 blows	1.00 < Su < 2.00	
4	**(Very compact / medium density)** silty sand with clay intercalations, medium humidity	15 < Nspt < 30 blows	2,00 < Su < 4,00	
6	**(Hard / dense to very dense)** sands with clayey matrix, medium humidity	Nspt < 30 blows	Su < 4,00 Kg/cm2	

Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Figure No. 5.227 shows the geotechnical zoning for the area of influence of the project, according to the information of the geotechnical drilling which was classified with the results of the standard drilling resistance and the resistance to the not drained cut.

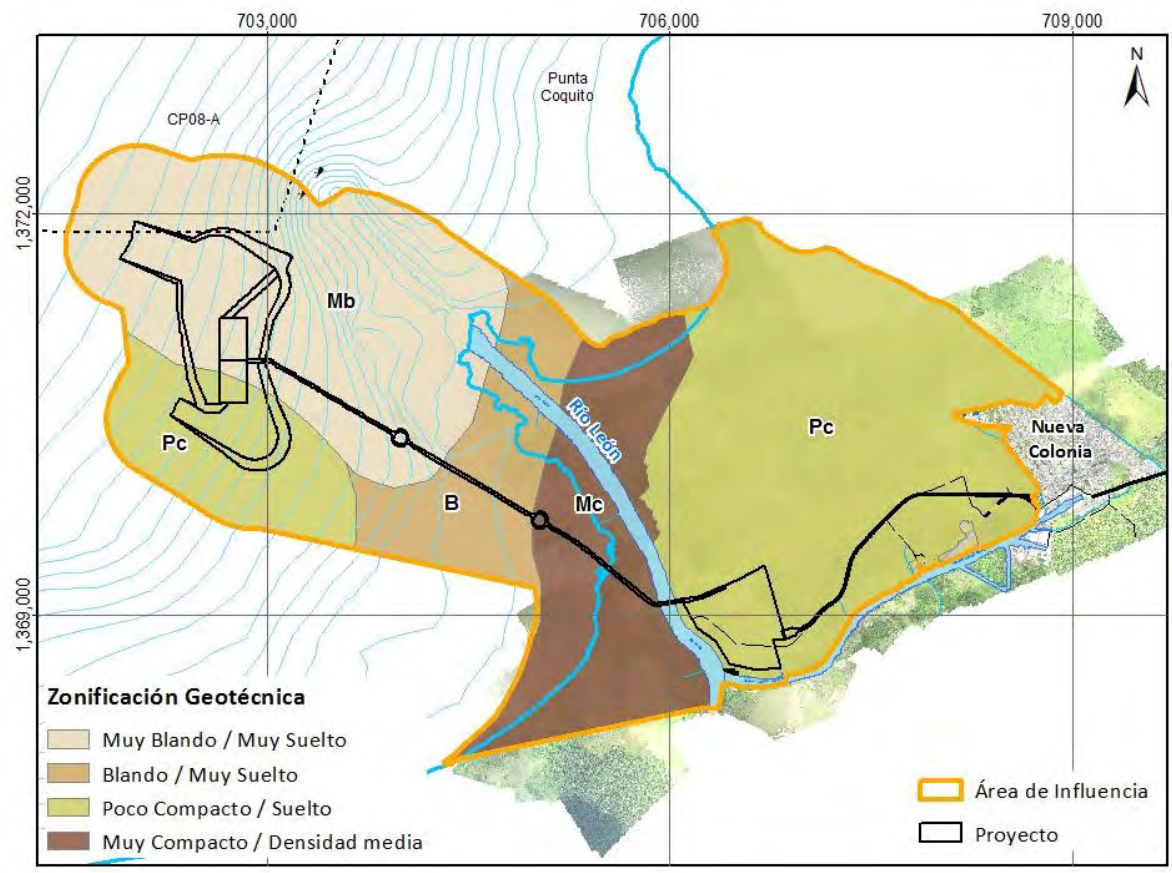


Figure No. 5.207 Geotechnical Zoning
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Geotechnical zoning

Very soft / Very loose

Soft/ Very loose

Little compact/ Loose

Very compact/ Medium density

Area of influence

Project

Below are the main findings of these studies for the project study area:

- *Stratigraphy of the land in the project sector*

Soils of marine origin formed by intercalations of clays, silts, sands, and some gravel were found. The resistance of these materials tends to increase with the depth from

very soft condition of the fine soils (clays and silts) and very loose (sands), up to firm consistency to hard and very hard in fine soils, and dense and very dense compactness in granular soils.

In the drilling on land, a large layer of very soft clays and silts was found up to 32 to 45 m depth, later a layer of clays with firmer sand, (32 meters and 55 meters), to reach the stratum loose to dense sands (between 55 meters and 60 meters) detected in PF-1 whose thickness varies laterally until it disappears, finally there is a new layer of clays between very firm to hard (between 60 meters and 80 meters). The presence of artesian water was detected in the lower strata.

In the water drillings, a layer of clays, very soft silts and very loose clayey silt sands was detected(a thickness of approximately 30 meters), then a layer of soft clays (from 35 meters to 42 meters), a layer of firm clays (up to 50 meters deep), following a layer of loose to dense sands (up to 65 meters) but that do not predominate in the entire profile, interspersed with a layer of firm clays (up to 70 meters), finally dense or hard sands (up to 80 meters) to hard clays to variable depths between 80 m and 100 m, which were the maximum depths reached in the exploration.

The middle and upper part of the explored strata correspond to normally consolidated or sub-consolidated soils. The CPT-F-1 and CPT-F-4 tests carried out on land show overconsolidation relationships close to one, which means that the soil is currently supporting the maximum effective effort to which it has been subjected throughout its history, which makes it particularly compressible to a high degree.

- *Piezometric level*

In the drillings on land where the presence of artesian water was detected, Casagrande type piezometers were installed, which were measured daily during the time that the exploration of the subsoil lasted since they were installed.

These piezometers should try to remain operational during the stages of studies and designs and also during the stages of construction and operation of the port as they will allow to evaluate the effectiveness of the systems applied to improve the terrain.

In the PF-2 drilling, a water sample was taken, and a physicochemical characterization was made, in Table No. 5.87 the results of this characterization are presented.

Table No. 5.79 Characterization of artesian water

Variable	Result
Copper	<0,05 mg/L
Color	< 5 UPC

Chromium content	<0,05 mg/L
DBO	11 mg/L
E Coli	$10,8x10^2$ NMP/100ml
Total Iron	17,4 mg/L
Mercury	<0,002 mg/L
Odor	Acceptable
Lead	<0,02 mg/L
Flavor	Acceptable
Total solids	3.030 mg/L

Source: Edifica Colombia Ltda.

- *Local seismic response analysis*

- Seismic Threat

The Colombian Seismic-Resistant Construction Regulation NSR-10 classifies Nueva Colonia as a zone of high seismic risk. The parameters of effective maximum acceleration of the terrain and the effective peak velocity for a probability of 10% of exceedance over a period of 50 years are Aa = 0.35 and Av = 0.1 respectively.

- Spectrum of Local Seismic Response

The analyzes performed showed that the response spectrum of the output signals of the analyzes corresponds to a 5% damping. The analyzes were based on a probability of 10% over a period of 50 years, that is, a return period of 475 years.

- Liquefaction Analysis

The results obtained from the liquefaction analyzes indicate that the subsoil profile in the PF-1 drilling located on land, PF-4 in the left support area of the bridge over the León River, and PF-6 located in the K1 + 120 of the viaduct is liquefiable in its loose sands strata. On the contrary, the rest of the drillings are not susceptible to liquefaction, which is due to the fact that the soils are only clayey or with deep dense sands.

However, the liquefaction potential does not seem to affect the foundations in PF-4 and PF-6 because they are deep piles supported by competent strata and for which the contribution in static resistance by friction in the shaft of the piles is very small.

Only one of the 3 drillings made on land, the PF-1 shows liquefiable strata in the upper part of the profile up to 2 m deep. The detailed geotechnical study carried out for the port with a greater number of drillings will give more information about the lateral extension of this loose sandy stratum, or the presence of other similar lenses.

Depending on the extent of the sandy strata, it may be necessary to use densification measures.

5.1.11 Atmosphere

- *Meteorology*

Colombia is located in the tropical zone, being part of the Hadley cell, which extends from the Equator to latitudes of about 30 ° in both hemispheres. The heat is transported in a cellular movement with the air ascending by convection in the equatorial regions and moving to higher latitudes through the upper layers of the atmosphere. The rise of warm air at the equator is accompanied by the frequent formation of convective storms in the so-called intertropical convergence zone -ZCIT (see Figure No. 5.228). Additionally, this region is subject to intense solar radiation, becoming the engine responsible for global air movement.

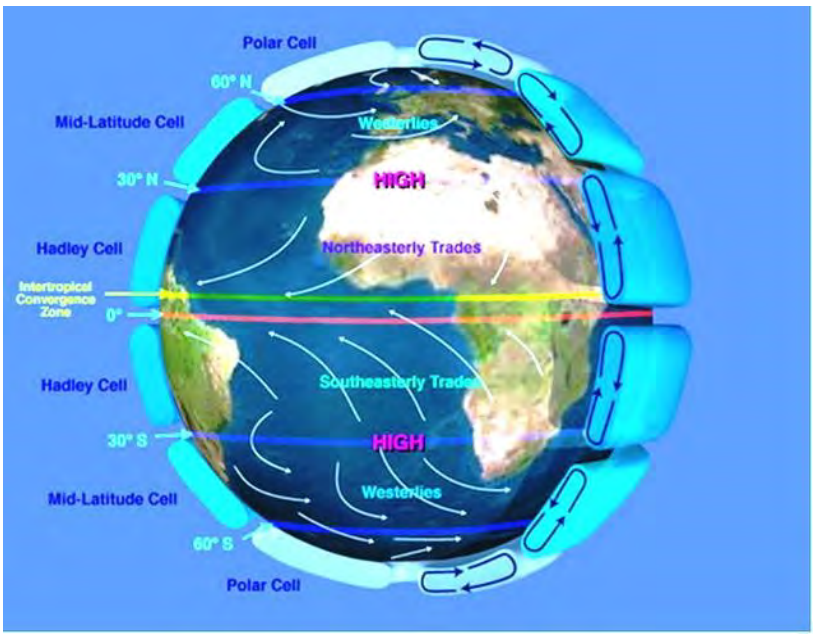


Figure No. 5.208 General circulation in the Earth's atmosphere. The Hadley subtropical cell, the Ferrell cell and the polar cell. The trade winds are shown coming from the subtropical latitudes blowing towards the Ecuador, being modified towards the West by the terrestrial rotation
Source: NASA, s.d.

The trade winds blow in the regions between the tropics, by the pressure differences between the tropical zones (High pressure) and equatorial (Low pressure). In the Northern Hemisphere the action of the Coriolis force diverts the air that goes in the direction of the Ecuador to the right forming the Northwest Trade Winds. Similarly, in the Southern Hemisphere the winds are diverted to the left originating the Southwest Trade Winds. Although the direction of the Trade winds can vary by topographical barriers, these winds are characterized by their regularity in the oceanic zones.

The ITCZ is a confluence of hot and humid air currents from mid-latitudes (subtropical) of both hemispheres. This is presented as a set of conglomerates of clouds with scales of the order of hundreds of kilometers, which are separated by regions of relatively clear skies; its intensity is variable in terms of time and space[223]. When this "cloud strip" is located over Central and South America, it produces strong rains and light winds in the Colombian Caribbean and, when it is located in the Southern Hemisphere between December and April, it generates strong and uniform winds called Northeast Trade Winds that dominate the Caribbean with a marked decrease in rainfall[224].

The Intertropical Convergence Zone moves latitudinally (Figure No. 5.229), following the apparent displacement of the sun with respect to the Earth, with a delay of approximately two months. On Colombia and neighboring areas, the segment of the eastern Pacific Ocean reaches its extreme southern position at 2 ° N between January and February. While in December it is a little further north, but this extreme position can reach 5 ° S during El Niño-Southern Oscillation events (ENSO). Between March and May the Pacific segment moves to the North and its position near the coast is between 2 and 7 ° N; the continental branch connects between March and April with the Atlantic Ocean segment forming a single system that is located between 5 ° S and 1 ° N in the East of the country; these two segments come together through convective conglomerates not very well organized over the Andean region. Between June and August the Pacific segment, at the beginning of the period is located at 8 ° N and at the end of the period at 10 ° N, penetrating the Caribbean region; the continental segment presents a southwest - northeast slope on the east of the national territory, also moving towards the North and passing from the Ecuador at 8 ° N. Between September and November, the Pacific segment begins its shift to

[223] LEON, G., ZEA J., ESLAVA, J. General circulation of the tropics and the Intertropical Confluence Zone in Colombia. Colombian Meteorology, 2000. 1:31-38

[224] PUJOS, M., PAGLIARDINI, J., STEER, R., VERNETTE, G., WEBER, O. Influence of the Colombian north counter-current for the circulation of water on the continental shelf: its action on the dispersion of effluents suspended from the Magdalena River. In Scientific Bulletin. CIOH.6:3-15. 1986.

the South and positions are recorded from 11 to 7 ° N; the continental branch also begins its journey towards the South, moving from 8 ° N to Ecuador over the Orinoquia and Amazonia, slowly losing its inclination until it almost coincides with the lines of the parallels; in this case also the two segments of the ITCZ are connected by means of convective conglomerates. As it passes through the different regions, the ITCZ determines the rainy seasons in Colombia.

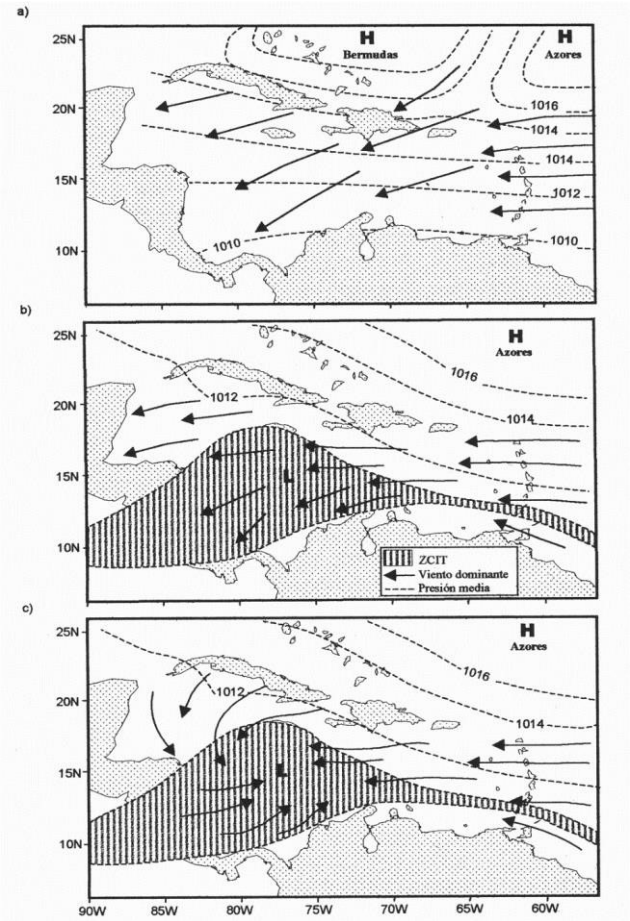


Figure No. 5.209 Movement of the Intertropical Convergence Zone (ITCZ). a) Wind season (December-March). b) Transition (April-July). c) Wet or rainy season (August-November))
Source: Andrade, 2000[225]

[225] ANDRADE, C.A., BARTON, ED. Eddy development and motion in the Caribbean Sea. J. Geophys. Res.,2000. 105(26):191–201

According to the climatic variations associated to the movement of the ITCZ the study area, three different climatic periods are differentiated:

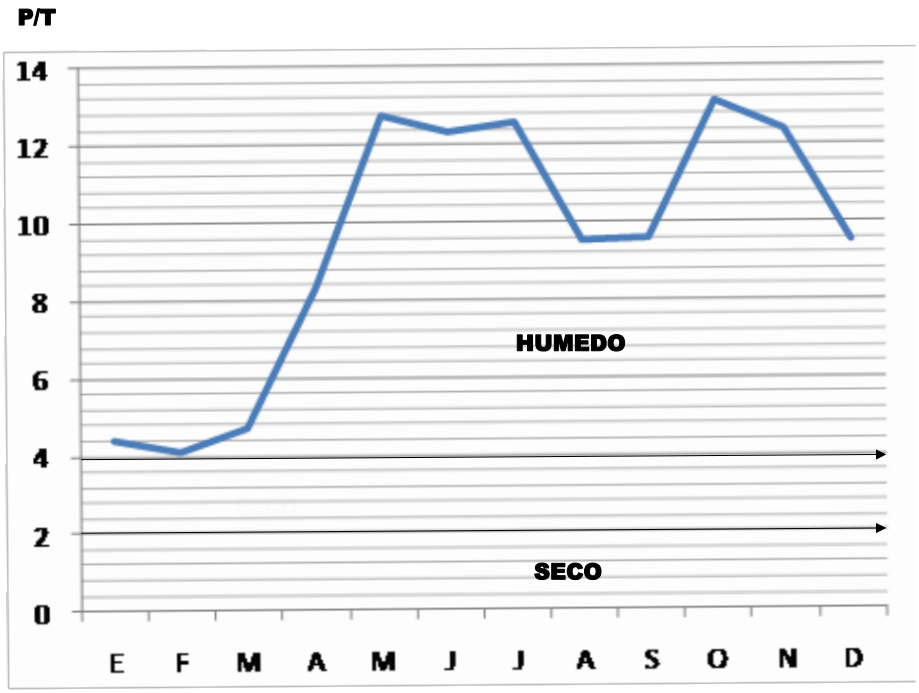
1) Dry period, between December and April (predominance of more intense winds and low rainfall rates): when the ITCZ is located over South America and the Caribbean the high pressure centers are strong, the trade winds of the NE are maximum reaching, in general, 15 to 19 knots of intensity (8 to 10 m / s) (Pets et al., 2007) and, sometimes, they exceed these values reaching up to 30 knots (15.4 m / s) (CIOH, 2010) . In this time there is influence of the San Andrés stream.

2) Humid period, between August and November (rainy, with a less intense wind predominance): it coincides with the period of greatest intensity of the Chocó stream; the ITCZ changes towards the center of the Caribbean, the trade winds weaken, and SW winds prevail, which are weaker but can bring strong storms towards the Caribbean region (Andrade and Barton, 2000).

3) Transition period, between May and July: also known as "Veranillo de San Juan": in which there is a second maximum of the San Andrés stream, which is not directly related to the ITCZ, but with a temporary intensification of the North Atlantic high-pressure system (Giannini et al., 2000). This period is characterized by a variability in rainfall and in the intensity and direction of the wind (CIOH, 2010).

This atmospheric behavior means that the humid tropical climate predominates in the region of the Gulf of Urabá, Bahía Colombia and the north of the department of Chocó, as can be seen in the Lang[226] aridity index diagram, where the monthly averages of precipitation are related. mm above the monthly averages of the average air temperature in ˚C. (See Figure No. 5.230)

[226] LANG, R. Verwitterung und Bodenbildung in die Boedenkunde. Stuttgart: 1920. En: DANTIN, J. y REVENGA, A. The lines and arid areas of Spain, according to the thermopluviometric indexes. Advance to the study of aridity in Spain. 1941.



Humid ----------Dry

Figure No. 5.210 Lang aridity index diagram: characterization of the climate in the Gulf of Urabá region

Source: ARAÚJO IBARRA based on the data of the meteorological parameters of the Apartadó station of IDEAM (1989-2008).

The climatic description presented below was obtained from the environmental impact[227] study carried out by Araújo Ibarra & Asociados S.A to obtain the Environmental License of the project obtained through Resolution 0032 of 2012[228]

- Precipitation:

The Gulf of Urabá region is characterized by being one of the wettest in Colombia, registering two well-defined rainfall peaks during the year: the first that begins in the month of April and ends in the month of July and the second that is evidence during the month of October, the rainiest of the year with around 350 mm, and in November as well. When the ITCZ exceeds the study area and moves to the south, precipitation

[227] PUERTO BAHÍA COLOMBIA DE URABA S.A. and ARAÚJO IBARRA & ASOCIADOS S.A. Environmental impact study for the construction and operation of a port terminal of solid bulk cargoes. Turbo. 2010. 428 p

[228] COLOMBIA. AUTORIDAD NACIONAL DE LICENCIAS AMBIENTALES – ANLA. Resolution 0032 (25, January 2012). By means of which an environmental license is granted. Bogotá, D.C. 135 p.

decreases, registering between the months of December to March a rainfall that does not exceed 150 mm. (See Figure No. 5.231)

On the other hand, INVEMAR and the Government of Antioquia, in the Atlas of the Gulf of Urabá[229], indicate an annual total rainfall of approximately 2,500 mm. They consider a distribution of monomodal monthly rainfall, with a rainy period, usually between May and November (250 mm / month in November), and a dry period, from December to mid-April (100 mm / month in February).

The authors point out that although it is true that there is a slight decrease in rainfall levels in the middle of the year - according to what was said above - especially in the months of June and July compared to those registered in May to November, does not correspond to a dry season like the one observed in the Andean region in the middle of the year, being more a transition stage from the dry to the rainy season.

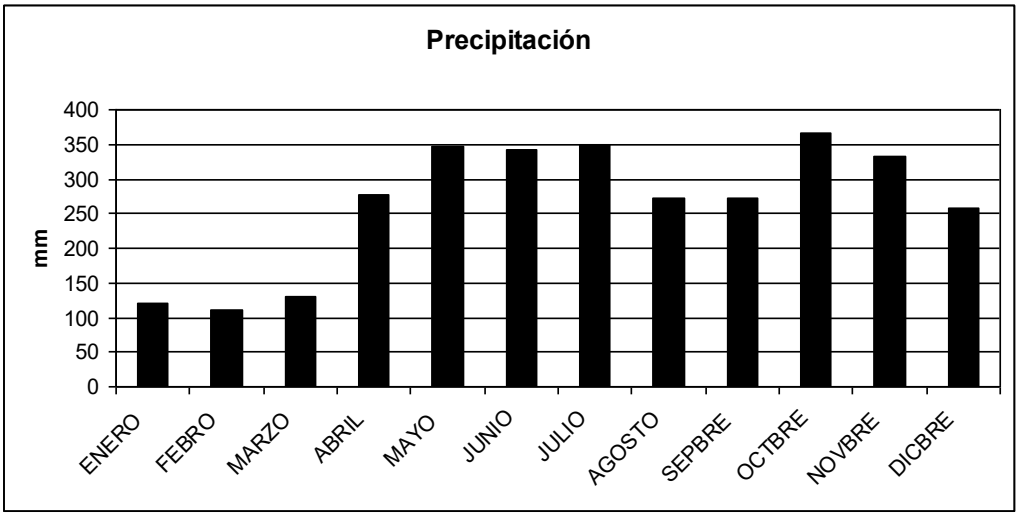


Figure No. 5.211 Average rainfall in the Gulf of Urabá (1989-2008)
Source: ARAÚJO IBARRA, Based on IDEAM records (Apartadó airport) (1989-2008).

Precipitation: January, February, March, April, May, June, July, August, September, October, November, December

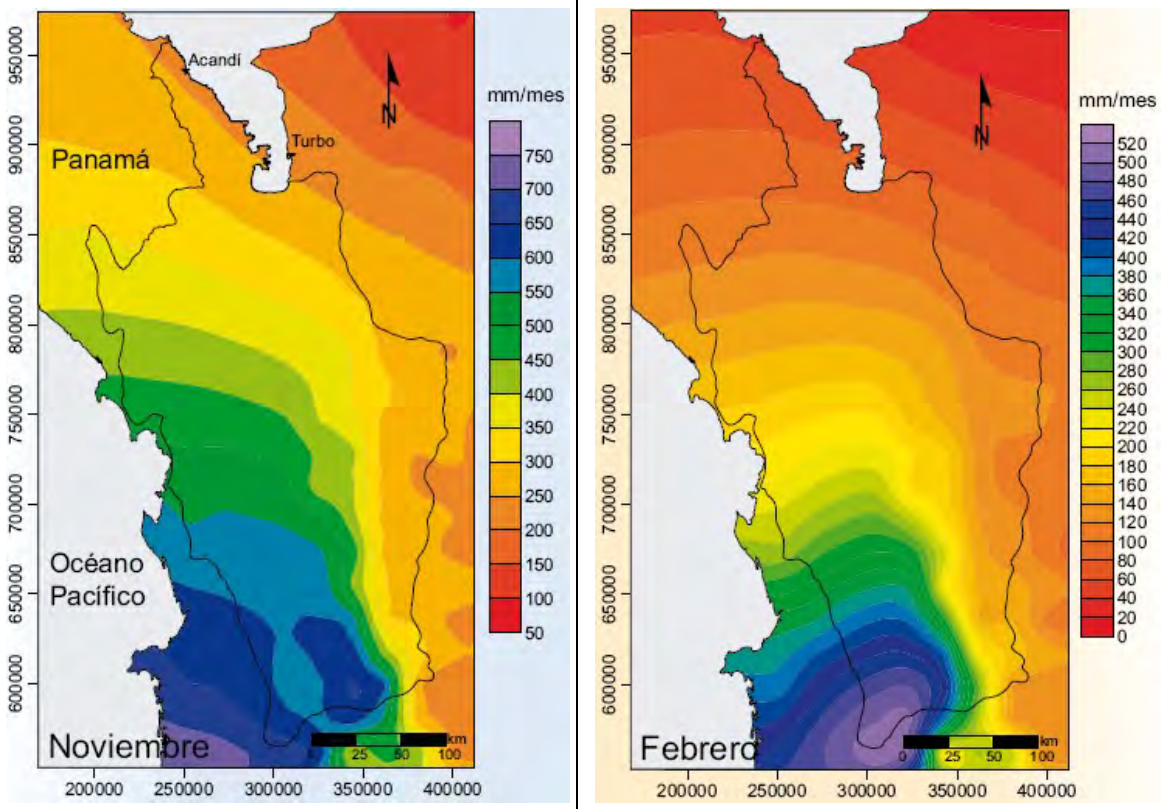
The Atlas of the Gulf of Urabá[230] contains diagrams of precipitation distribution (isohyets) (see Figure No. 5.232), which were prepared by their authors based on the study by Lozano (1998)[231], which provided statistical data on the gulf, and the

[229] INVEMAR. Atlas of the Gulf of Urabá, 2007. Op Cit.
[230] Ibíd.
[231] LOZANO, L. H. Characterization and integral diagnosis of the coastal zone that includes the Colombia Bay from the Turbo River to Matuntugo. Almirante Padilla Naval School, Faculty of Physical Oceanography: Cartagena de Indias, 1998. 283 pages.

works of New et al. (1999[232], 2000[233] and 2002[234]), who provided the cartography of the main climatological parameters for the Atrato river basin.

As can be seen in Figure No. 5.232, with less than 10 days in February, the number of days of humidity (rainfall ≥ 0.1 mm) increases to more than 15 over the eastern sector and up to 20 over the western sector of the gulf.

Wet season | Dry season



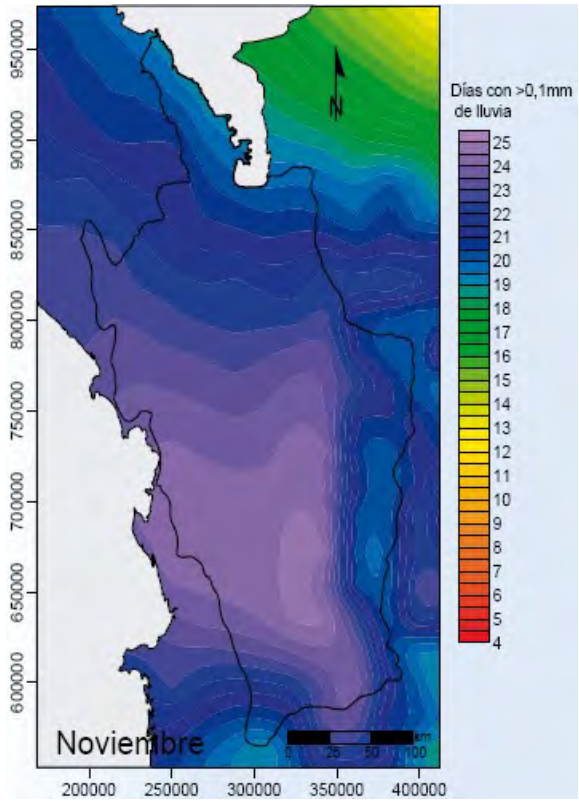
November | February

Figure No. 5.212 Distribution of precipitation in the Atrato River basin

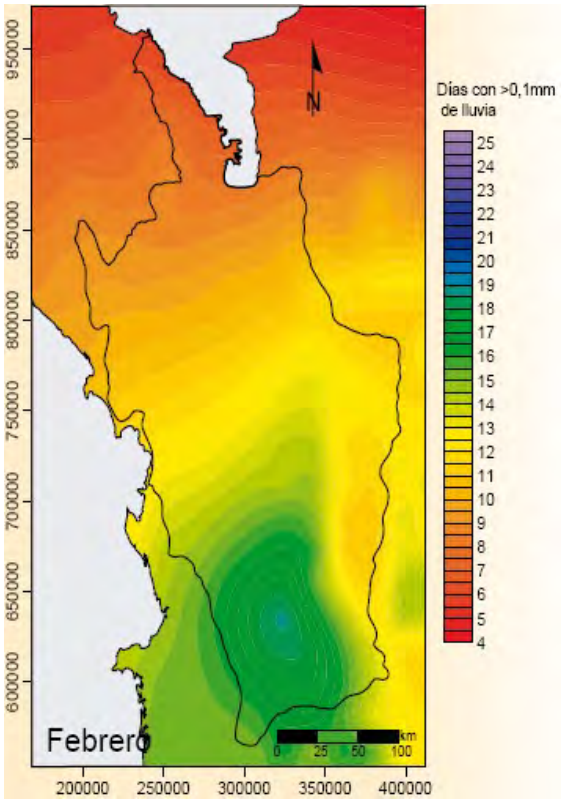
[232] NEW M., HULME, M. y JONES, P. Representing twentieth century space-time climate variability. Part I: Development of a 1961–90 mean monthly terrestrial climatology. On: Journal of Climate. Vol. 12 (1999); pages 829-856.
[233] NEW M., HULME, M. y JONES, P. Representing twentieth century space-time climate variability. Part II: Development of 1901-1996 monthly grids of terrestrial surface climate. On: Journal of Climate. Vol. 13 (2000); pages 2217-2238.
[234] NEW M., LISTER, D., HULME, M. y MAKIN, I. A high-resolution data set of surface climate over global land areas. On: Climate Research. Vol. 21 (2002); pages 1-25.

Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[235].

Wet season



Dry season



November February

Figure No. 5.213 Distribution of humidity days per month (with rainfall ≥ 0.1 mm) in the Atrato River basin

Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[236].

[235] INVEMAR. Atlas of the Gulf of Urabá, 2007. Op Cit.

[236] Ibíd.

- Temperature:

Figure 5,234 shows the annual fluctuation of the temperature, with information collected for 19 years by the IDEAM at the climatological station of the Apartadó airport, Antioquia.

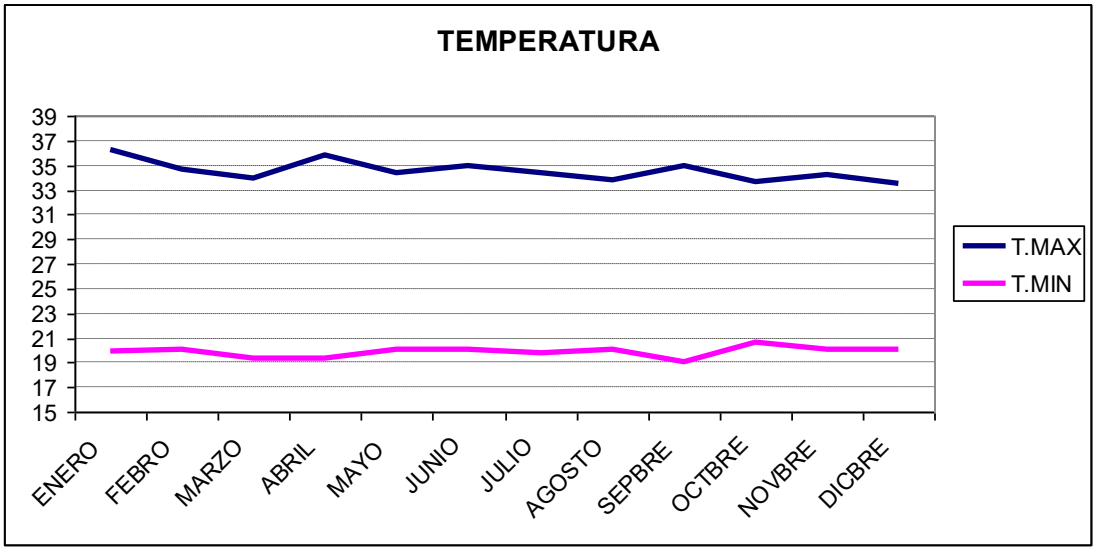


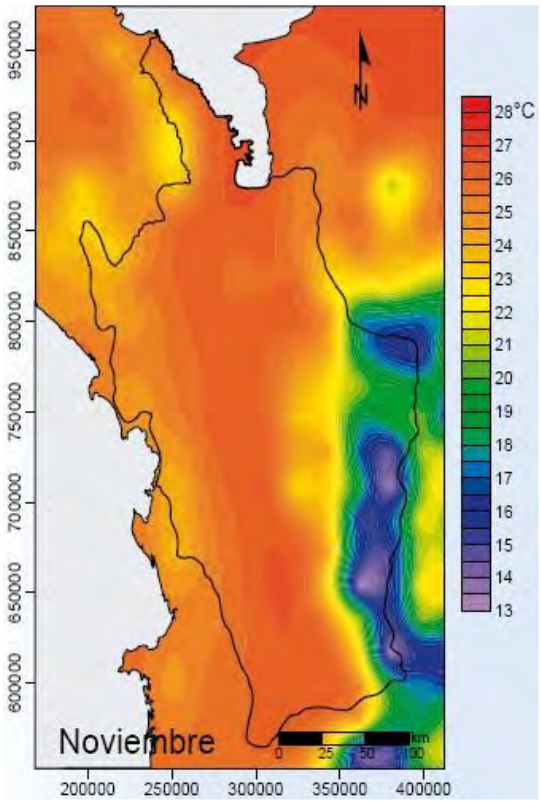
Figure No. 5.214 Maximum and minimum temperatures (1989-2008)
Source: IDEAM Registries (Apartadó airport) (1989-2008).

TEMPERATURE: January, February, March, April, May, June, July, August, September, October, November, December

Below is the distribution of the temperature in the Atrato basin, according to the diagrams prepared in the Atlas of the Gulf of Urabá[237], which indicates a very weak seasonal thermal variability in the gulf, characteristic of the equatorial zone and the proximity of the ocean mass, which moderates intraday changes. This is how it reports fluctuations in the narrow range of 26-28º C, with maximum temperatures between March and June and minimum temperatures in February, August and October.

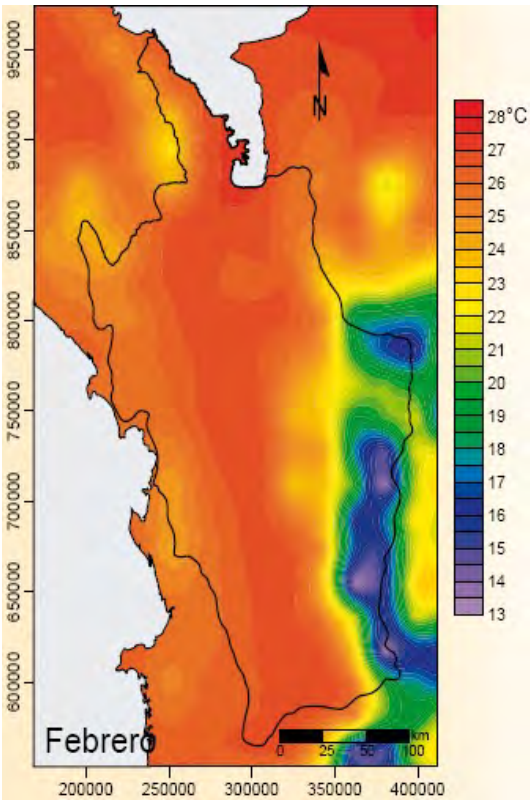
[237] Ibíd.

Wet season



November

Dry season



February

Figure No. 5.215 Distribution of daytime temperature in the Atrato River basin
Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[238].

- Winds:

The winds in the region of the Gulf of Urabá have a bimodal behavior, during the months from December to March. When the ITCZ reaches its southernmost position, with low pressure and cloudiness over the Colombian Pacific, a less humid time is generated for the region of the Gulf of Urabá and Bahía Colombia, with the predominance of the trade winds entering from the northwest and the North. (See Figure No. 5.235).

Between the months of April to November, when the ITCZ is located over the north of the Chocó and the Urabá region, the region of the Gulf of Urabá and Bahía

[238] Ibíd.

Colombia is characterized by a high cloudiness and precipitation, with the presence of winds coming from the south, southeast and southwest. (See Figure No. 5.235).

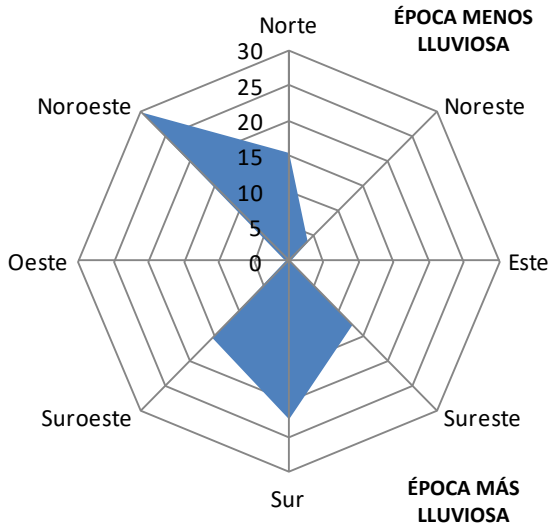


Figure No. 5.216 Wind rose dry- wet seasons (Matuntugo Station-Gulf of Urabá)
Source: ARAÚJO IBARRA & ASOCIADOS S.A with the meteorological data of the Matuntugo Station, for the years 2007 and 2008[239],

The bimodal behavior of the winds in direction is also observed in its speed. During the less rainy season the winds are more intense, registering 45% of the time with speeds between 11 and 17 knots[240], while during the wettest season they record speeds between 4 and 7 knots 51% of the time, and only in 2% of the time, with speed records between 11 and 17 knots. (See Figure No. 5.237 and Figure No. 5.238).

[239] ARAÚJO IBARRA & ASOCIADOS S.A with the meteorological data of the Matuntugo Station, for the years 2007 and 2008. In: Meteomarino Bulletin of the Oceanographic and Hydrographic Research Center CIOH of the National Navy of Colombia.

[240] 1 knot = 1,852 km/h = 0,514444 m/s.

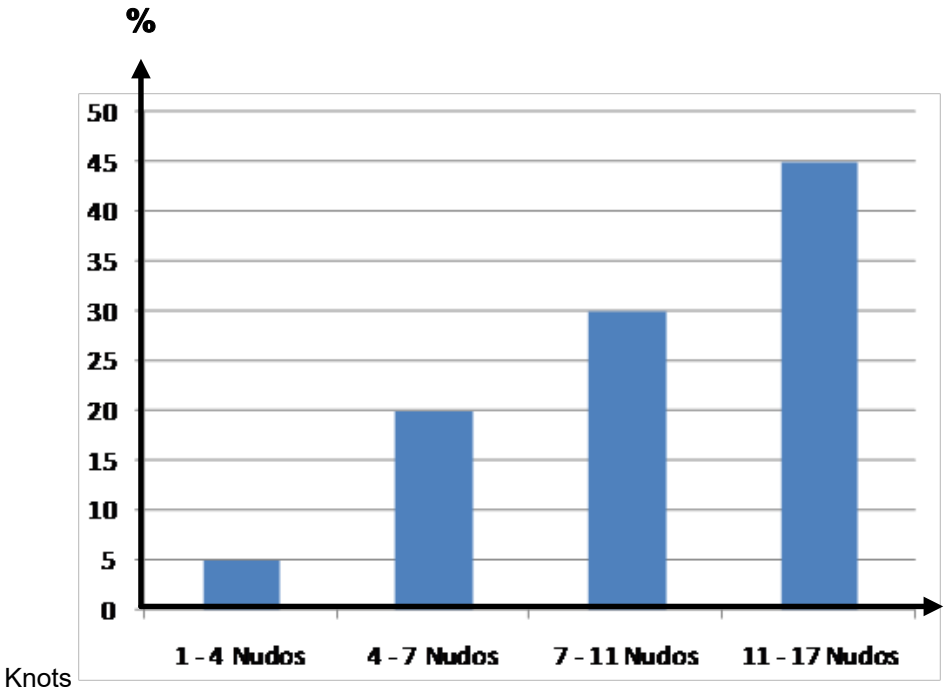


Figure No. 5.217 Frequency of wind speed during the less rainy season (Matuntugo station, Gulf of Urabá)

Source: ARAÚJO IBARRA & ASOCIADOS S.A with the meteorological data of the Matuntugo Station, for the years 2007 and 2008[241],

[241] ARAÚJO IBARRA & ASOCIADOS S.A with the meteorological data of the Matuntugo Station, for the years 2007 and 2008. Op Cit.

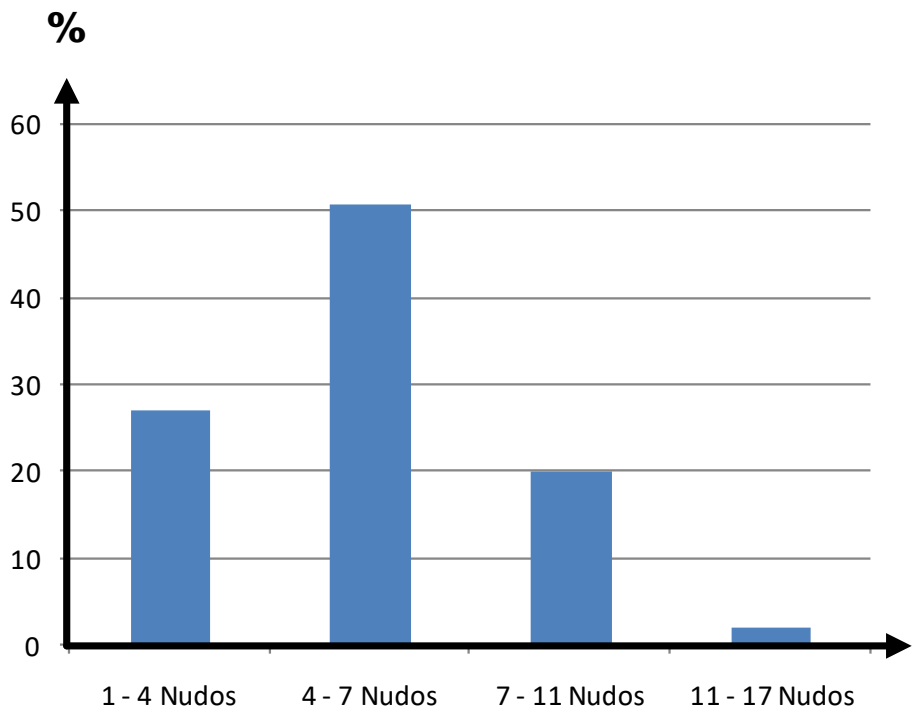


Figure No. 5.218 Frequency of wind speed during the rainy season (Matuntugo station, Gulf of Urabá)

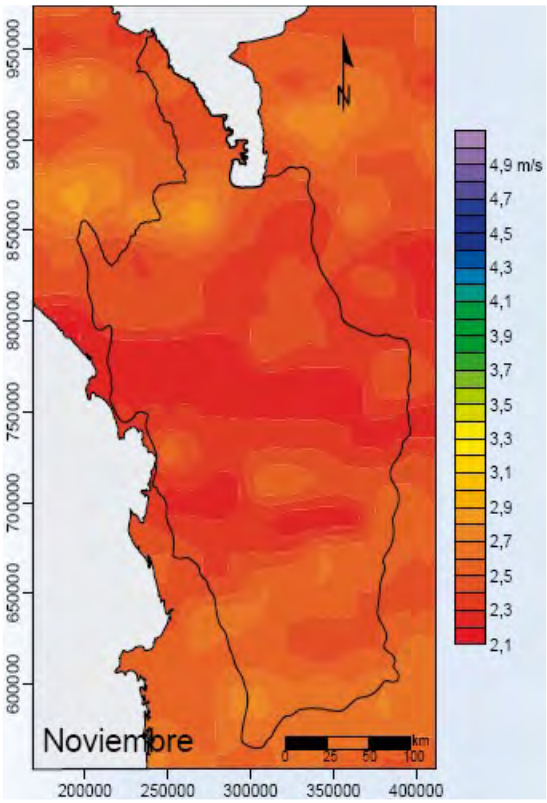
Source: ARAÚJO IBARRA with the meteorological data of the Matuntugo CIOH Station, for the years 2007 and 2008.[242]

Below is the distribution of wind speed in the Atrato basin, according to the diagrams prepared in the Atlas of the Gulf of Urabá[243]: Figure No. 5.239 shows average values of 3 to 4 m/s between January and March (dry season) and lower speeds 2 m/s in rainy season (weak winds, with very variable directions and low stability). As mentioned above, in the dry season, the North and North East trade winds present their maximum intensity, reaching speeds of over 7 m / s, including periods up to 24 hours in which the speed exceeds 10 m/s.

[242] ARAÚJO IBARRA & ASOCIADOS S.A with the meteorological data of the Matuntugo Station, for the years 2007 and 2008. In: Monthly Meteomarino Bulletin of the CIOH Oceanographic and Hydrographic Research Center, of the Colombian National Navy

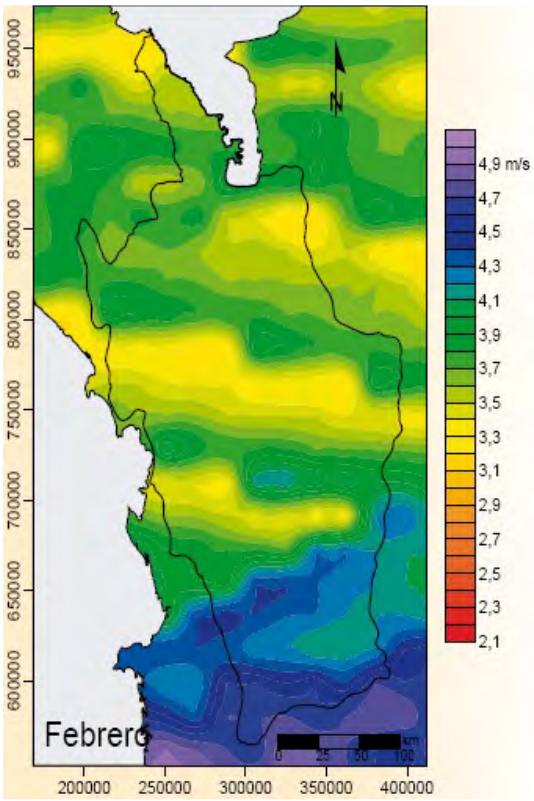
[243] INVEMAR. Atlas of the Gulf of Urabá, 2007. Op Cit.

Wet season



November

Dry season



February

Figure No. 5.219 Distribution of wind speed in the Atrato River basin

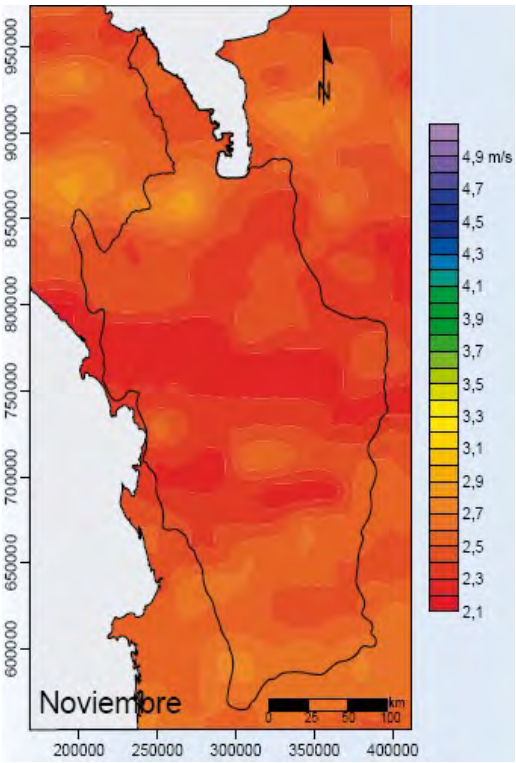
Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[244].

- Solar brightness:

According to the Atlas of the Gulf of Urabá[245], the solar brightness estimates in the Atrato River basin give an approximate annual total of 1,924 hours of sunshine (5 hours a day on average), a high value for the Colombian territory, favorable to the establishment of agroindustrial crops. As a percentage of the maximum possible, the solar brightness varies between 35 and 40% in November and between 50 and 55% in the month of February.

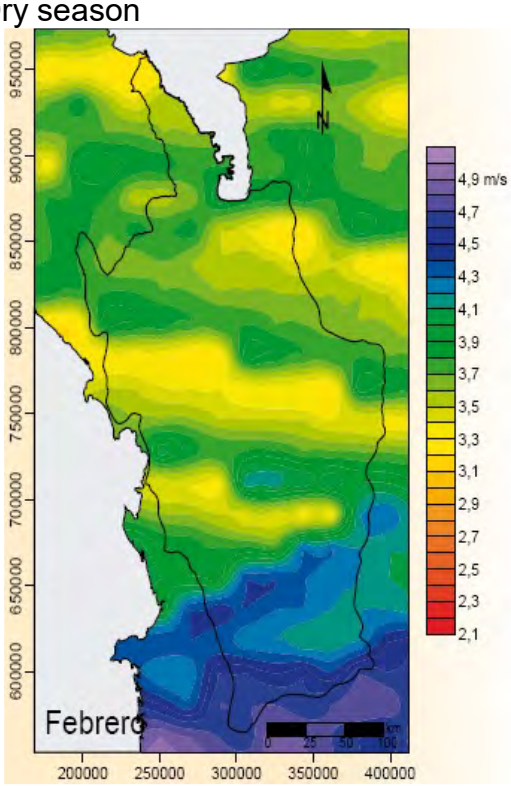
[244] Ibíd.
[245] Ibíd.

Wet season



November

Dry season



February

Figure No. 5.220 Distribution of solar brightness in the Atrato River basin

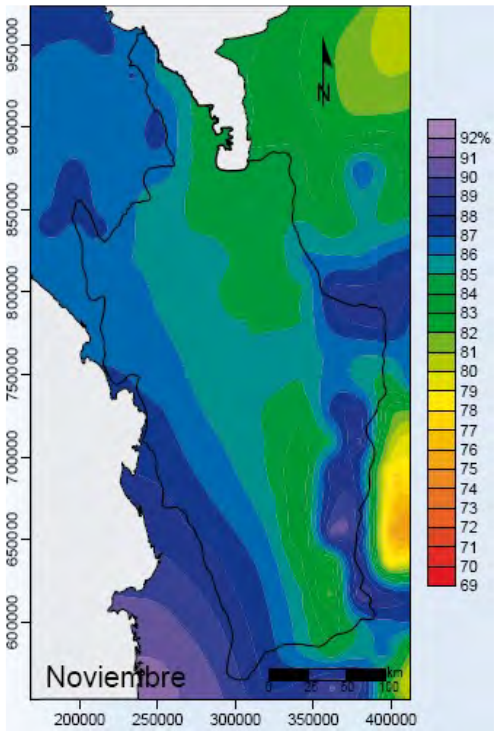
Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[246].

- Relative humidity:

According to the distribution curves in the Atrato basin presented in the same document, the relative humidity, widely marked by the presence of the oceanic mass, remains basically unchanged during the year, with average monthly values between 86% in November (wet season) and 80% in February (dry season).

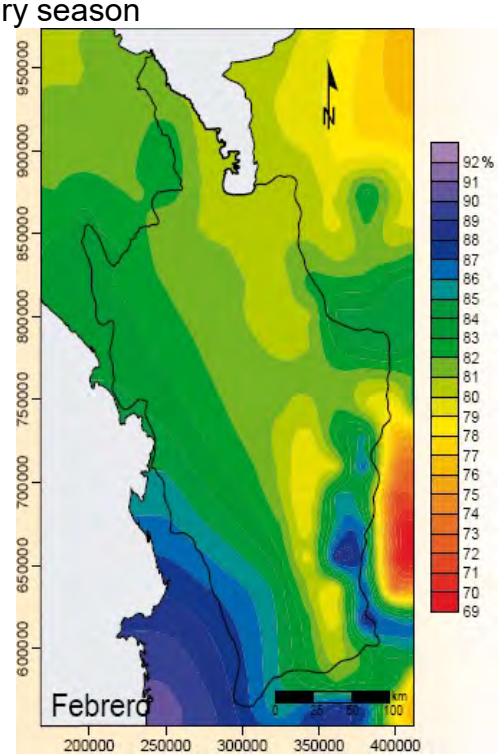
[246] Ibíd.

Wet season



November

Dry season



February

Figure No. 5.221 Distribution of relative humidity in the Atrato River basin

Source: INVEMAR. Atlas of the Gulf of Urabá, 2007[247].

- Evaporation

The steam enters the atmosphere through the processes of evaporation and transpiration and then returns to the earth in the form of rain, closing the hydrological cycle. In meteorology, evaporation means the emission of steam from a liquid surface of free water, at a temperature below the boiling point[248].

At the regional level, the evaporation in the study area presents a multi-year average of 900 - 1100 mm according to the historical records between the years 1981 - 2010, as can be seen in Figure No. 5.242.

To the north and center of the region of Antioquia, there is a maximum of evaporation during the first quarter of the year and minimums in the rainiest months of October-

[247] Ibíd.

248 INSTITUTO DE HIDROLOGÍA, METEOROLOGÍA Y ESTUDIOS AMBIENTALES –IDEAM. Climatological Atlas of Colombia. [Online] <http://bart.ideam.gov.co/portal/prono_fin_semana/meteorologia/> [Consulted August, 20, 2015]

September and April-May. In the south of the region, the highest values tend to occur in the months of July, August and September and monthly minimums in October and November, although in certain cases there are appreciable decreases in March or April. In the whole region, the maximum values can generally oscillate around 5 mm daily and the minimum values are of the order of 3 mm daily, on average.

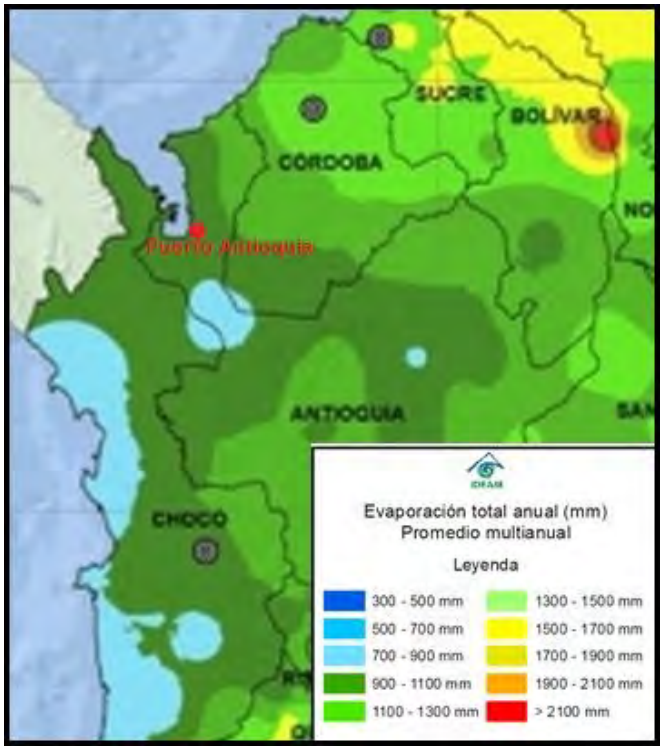


Figure No. 5.222 Annual total evaporation (mm) multi-year average (1981-2010)
Source: IDEAM, 2014[249]

- Tropical storms

The Caribbean Sea region is characterized by the formation of tropical cyclones. Traditionally, hurricanes develop over warm waters between June and November, due to the convergence of the Trade winds on the West Coast of Africa (Mo et al.,

[249] INSTITUTO DE HIDROLOGÍA, METEOROLOGÍA Y ESTUDIOS AMBIENTALES –IDEAM. Climatological Atlas of Colombia. Total annual average evaporation map 1981-2010. [Online] <http://bart.ideam.gov.co/portal/prono_fin_semana/meteorologia/> [Consulted August, 20, 2015]

2001), However, Shapiro and Goldenberg (1998)[250] and Goldenberg et al. (2001)[251] analyzed the relationship between the sea surface temperature (SST) and the formation of cyclones in the Atlantic, showing that there is no correlation between temperature and the formation of cyclones. Tropical cyclones are classified according to the *Saffir-Simpson* scale according to the speed of the winds (see Table No. 5.88).

Table No. 5.80 Classification of Tropical Cyclones according to the *Saffir-Simpson* scale

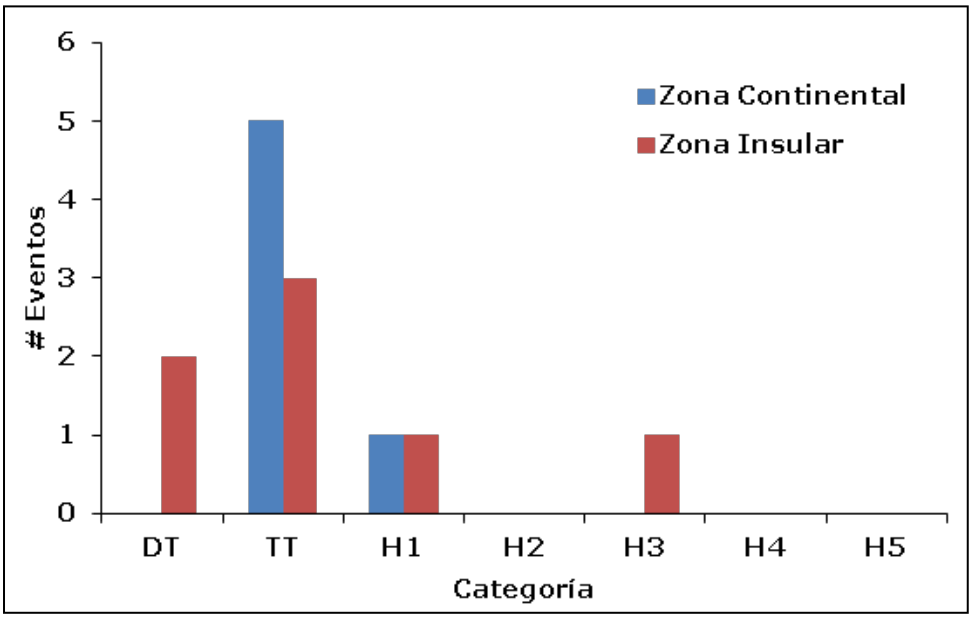
CLASSIFICATION	WIND SPEED (km / h)
Tropical Depression (DT)	<63
Tropical Storm (TT)	63 – 117
H1	119 – 153
H2	154 – 177
H3	178 – 209
H4	210 – 249
H5	>250

Source: National Hurricane Center, s.d[252].

The formation of tropical cyclones is deeply studied in the National Hurricane Center (United States of America) due to its economic and social importance. With the exception of the San Andres and Providencia Islands region, the Colombian Caribbean has been considered as an area of low probability and development of tropical storms, according to the National Oceanographic and Atmospheric Administration (NOAA), being extremely rare that a tropical storm or hurricane touches the north coast of South America[253].

Ortiz (2012)[254] conducted an analysis of the hurricanes that have touched the Colombian coast between 1900 and 2010, concluding that a total of 10 storms have affected the Caribbean coast of Colombia in this period. In the continental area there has been six storms (5 tropical storms and one hurricane category 1) and seven events registered (2 tropical depressions, 3 tropical storms, one hurricane category 1 and one hurricane category 3) that affected the insular area (see Figure No. 5.232).

[250] SHAPIRO, LI.J, GOLDENBER, S.B. Atlantic sea surface temperatures and tropical cyclone formation. J. Climante, 1998. 11: 578 – 590
[251] GOLDENBERG S.B., LANDSEA,C.W., MESTAS –NUÑEZ, A.M., GRAY., W.M. The recent increase in Atlantic Hurricane Activity: Causes and implications. Science., 2001. 293: 474 – 478
[252] PASCH, RJ. Preliminary report tropical storm Bret. 4 -11 august 1993. National Hurricane Center, NOAA. Miami, 1993. Fla., 14 p.
[253] GERRISH, H.P. Preliminary report hurricane Joan. 10 – 23 October 1988. National Hurricane Center, NOAA. Miami, Fla. 1988, 14 p.
[254] ORTIZ, J.C. Exposure of the Colombian Caribbean coast, including San Andrés Island, to tropical storms and hurricanes, 1900–2010. Nat. Hazards, 2012. 6: 815 – 827.



Events-----Category Continental Area(blue)--- Insular area(red)

Figure No. 5.223 Significant events that have affected the Colombian Caribbean (Insular and Continental) between 1900 - 2010

Source: Taken from Ortiz, 2012[255].

Following is the trajectory and a brief description of the main events that have passed through the Colombian Caribbean coast. The main events that have been recorded have been, a storm without a name that happened in June 1933, Irene 1971, Joan 1988 and Bret 1993 and Cesar in 1996[256].

Irene 1971: It formed on the west coast of Africa reaching quickly the Caribbean, where it loses intensity to meet the Windward Islands where it loses strength, after passing through the North Coast of Colombia gains strength to reach the category of hurricane (1) off the coast of Nicaragua[257] (see Figure No. 5.233).

[255] Ibíd.
[256] ORTIZ, J.C. 2007. Hurricanes and Tropical Storms in the Colombian Caribbean Sea since 1900. In the Scientific Bulletin CIOH. 25:54-60., 2007
[257] SIMPSON, R.H., HOEP., J.R. Atlantic hurricane season of 1971. National Hurricane Center, NOAA. Miami, Fla.1971, 20 p

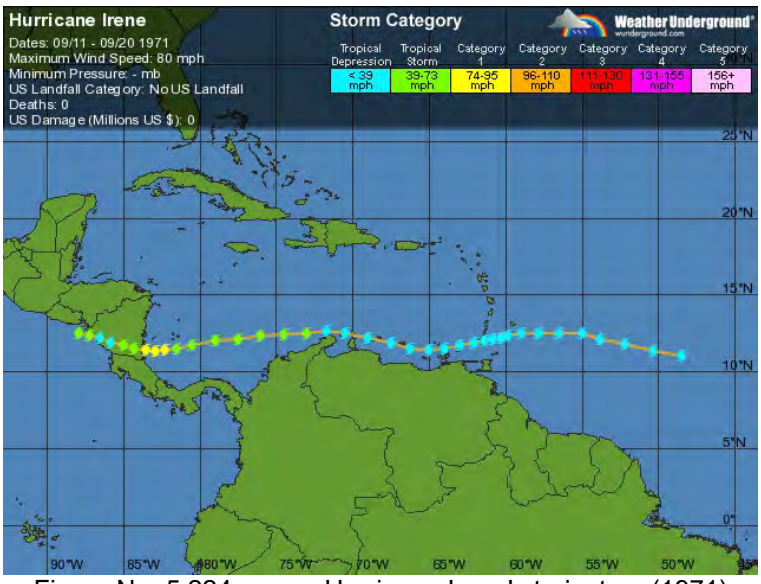


Figure No. 5.224 Hurricane Irene's trajectory (1971)
Source: Weather Underground, 2012.

Hurricane Joan (1988): reached hurricane conditions on the west coast of the La Guajira Peninsula at 30 nm (nautical miles) off the coast of Colombia, although when passing through the Colombian coast was a tropical storm, the rain that accompanied the storm caused severe flood damage, leaving a total of 25 dead and approximately 27,000 displaced persons[258] when it passed through the country (see Figure No. 5.234).

[258] GERRISH, H.P. 1988. Preliminary report hurricane Joan. 10 – 23 October 1988. National Hurricane Center, NOAA. Miami, Fla., 1988. 14 p

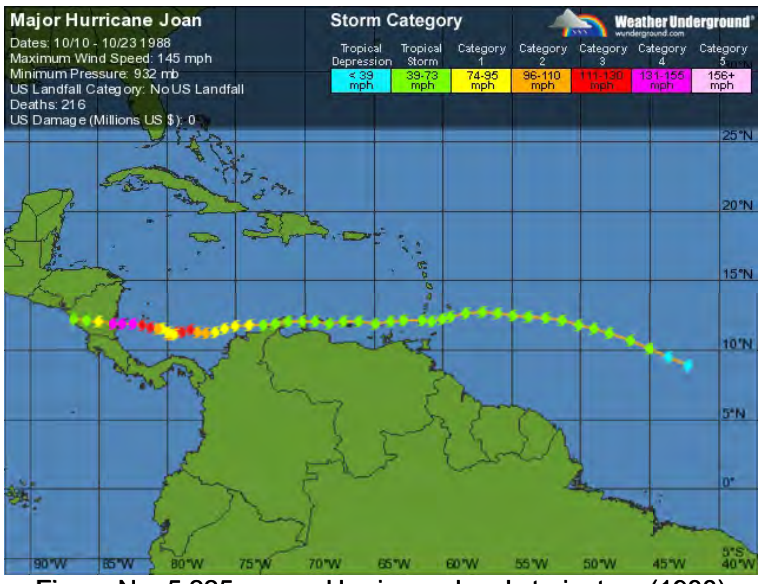


Figure No. 5.225 Hurricane Joan's trajectory (1988)

Source: Weather Underground, 2012.

Hurricane Bret (1993): touched land on the Venezuelan coast and continued its path to Colombia, path to Colombia, where it meets the high elevations of the Sierra Nevada de Santa Marta, causing Marta, causing a considerable weakening, however, after crossing this area gains strength again until strength again until reaching its maximum speed in front of to the Nicaraguan coast. On its way On its way through Colombia left a dead person and an injured person[259] (see November February

Figure No. 5.215).

[259] PASCH, RJ. 1993. Preliminary report tropical storm Bret. 4 -11 august 1993. National Hurricane Center, NOAA. Miami, Fla,.1993. 14 p

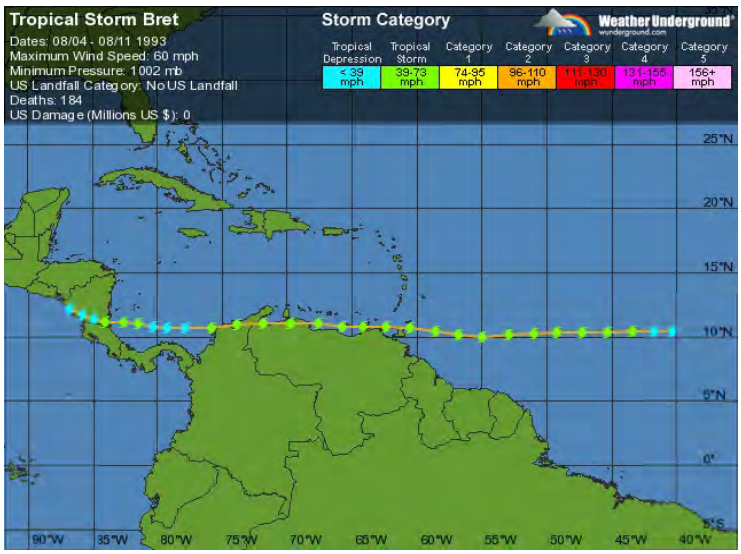


Figure No. 5.226 Hurricane Bret's trajectory (1993)

Source: Weather Underground, 2012.

Hurricane Cesar (1996): It is formed from a tropical wave that crossed Dakar, Africa moving towards the West, until it develops in the region of the Windward Islands. Cesar continued its path towards the West increasing its intensity, losing its intensity when approaching the coast of South America, and later it reaches hurricane category in the coast of Nicaragua, when crossing Nicaragua it arrives at the Pacific Ocean where it intensifies again and changes its name to Douglas[260] (see Figure No. 5.216).

[260] AVILA, L.A. Preliminary report hurricane Cesar. 24 – 29 July 1996. National Hurricane Center, NOAA. Miami, Fla., 1996. 11 p

Figure No. 5.227 Hurricane Cesar's trajectory (1996)

Source: Weather Underground, 2012.

From the information presented above it is possible to conclude that the region of the Gulf of Urabá has not been historically affected by tropical storms, which does not present a risk for the execution and operation of the project.

- *Identification of sources of atmospheric emissions*

The study area of the project presents little industrial intervention, it is an area with vocation of export-type plantain and banana crops, where flows of land, fluvial and maritime traffic are related to transportation to the vessels in Bahía Colombia.

The industries that are located in the area of influence of the project are located in the District of Nueva Colonia (Uniban and Banacol), which have a jetty, storage area and offices, that is where the aforementioned crop productions are collected, to proceed with the transfer through the Bananeros Convoy to the anchorage area, where the export ships are located.

- Fixed Sources

The presence of emissions of gases and particulate material by fixed sources in the study area of the project, District of Nueva Colonia and project land located within the jurisdiction of the municipality of Turbo was not evident.

- Mobile sources

Due to the presence of the banana companies in the district of Nueva Colonia and the transit of the same population of the district, the circulation of light vehicles such as automobiles and motorcycles, buses and heavy goods vehicles was evidenced. For the fluvial and marine transport there are boats, tugboats and ships.

According to the 2015 Puerto Bahía Colombia De Urabá Transit Study[261], the traffic flow between the section of the route of the Rio Grande district and the Nueva Colonia district presented a total of 1,912 vehicles / day, passing through this section, of which 268 are light vehicles and 1644 correspond to heavy vehicles (buses and trucks); This is equivalent to 86% of heavy vehicles and 14% of light vehicles. (See Annex 5.1.3 Estudio_Transito_Puerto Antioquia)

Additionally, for the dredging of the León River and the Canal Nueva Colonia, a dredge is constantly presented for the maintenance of the channel, in order to guarantee the navigability of the same.

- Area

The presence of emissions of gases and particulate material in a source area within the study area of the project, District of Nueva Colonia and project land located within the jurisdiction of the municipality of Turbo was not evident.

- *Air quality*

The compilation of the air quality information recorded in the Environmental Impact Study was carried out[262], with which the Environmental License for the project was

[261] PIO SAS y GRUPO VIAL. Basic and detailed engineering, procurement and supply of materials, construction, assembly and commissioning of the works required for phase 1 of the Puerto Antioquia Port Terminal located at the mouth of the León River, in the Gulf of Urabá - Transit Study, Department of Antioquia. Cali, 2015. 203 p.
[262] PUERTO BAHÍA COLOMBIA DE URABA S.A. and ARAÚJO IBARRA & ASOCIADOS S.A, 2010. Op Cit.

obtained, through Resolution 032 of 2012[263]. It should be mentioned that air quality sampling was not carried out, since the conditions of the intervention area did not vary according to the characteristics of the study area on the date of the monitoring in 2009 compared to the state in 2015, it does not present significant variations in terms of infrastructure, industries, vehicular flow and source of emission that could cause variations in the contamination to the environment, therefore, it was considered that it was not representative to perform again air quality monitoring for the modification of environmental license.

The company Air Clean Systems S.A. (ACS S.A.) was responsible for carrying out the air quality monitoring in the period between September 24 and October 4, 2009 (10 continuous days), in 3 stations of the Project site[264].

- Location of monitoring points:

The records taken from the air quality monitoring stations carried out by the company Air Clean Systems S.A. (ACS S.A.), were located in the following way, see Table No. 5.89, Figure No. 5.248 and the map MOD_LA_PTO_ANT_28_RuidoAire:

Table No. 5.81 Location of air quality monitoring stations

Stations	ID	NAME	FLAT COORDINATES MAGNA SIRGAS Origin BOGOTÁ	
			EAST	NORTH
1 (PST) y 4 (PM_{10})	A 1-4	North Sector	706516.54	1369224.56
2 (PST) y 5 (PM_{10})	A 2-5	South Sector	706430.13	1368659.23
3 (PST) y 6 (PM_{10})	A 3-6	Center	706490.39	1368972.54

Source: Aqua & Terra consultores Asociados S.A.S., 2015 with data from ARAÚJO IBARRA, 2009.

[263] COLOMBIA. AUTORIDAD NACIONAL DE LICENCIAS AMBIENTALES – ANLA. Resolution 0032 (25, January, 2012). By means of which an environmental license is granted. Bogotá, D.C. 135 p.
[264] AIR CLEAN SYSTEMS S.A. (ACS). Air quality evaluation report for Puerto Bahía Colombia de Urabá S.A. ACS ICA 126. October 2009.

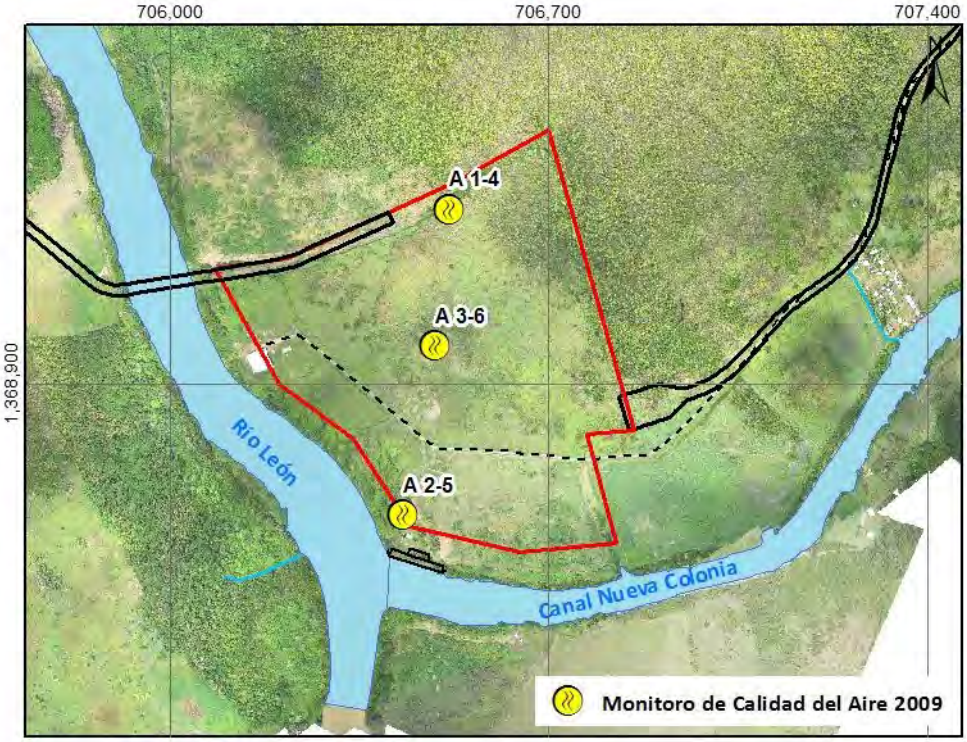


Figure No. 5.228 Location of air quality monitoring stations
Source: Aqua & Terra consultores Asociados S.A.S., 2015 with data from ARAÚJO IBARRA, 2009.

- Permissible limits

A comparative analysis of the results of the monitoring will be carried out with the Colombian regulations, Resolution 610 of 2010[265], issued by the Ministry of Housing, Environment and Territorial Development, now the Ministry of Environment and Sustainable Development, which establishes the permissible limits for concentrations of pollutants in the air (criteria pollutants) (see Table No. 5.90), established at reference conditions 25 ° C and 101,325 kPa:

Table No. 5.82 Maximum permissible levels for criteria pollutants in immission air

Pollutant	Maximum allowable limit in µg / m³ (at 25 ° C and 101,325 kPa)	Averaging time
PST	100	Annual
	300	24 hours

[265] COLOMBIA. MINISTERIO DE VIVIENDA, AMBIENTE Y DESARROLLO TERRITORIAL. Resolution 610 (march, 24, 20101). By which Resolution 601 of April 4, 2006 is modified. Bogotá D.C., 2010

PM_{10}	50	Annual
	100	24 hours
SO_2	80	Annual
	250	24 hours
	750	3 hours
NO_2	100	Annual
	150	24 hours
	200	1 hour
CO	10.000	8 hours
	40.000	1 hour

Source: Resolution 610 of 2010 of the MAVDT [266].

- Weather conditions:

During the monitoring period, climatic data representative of local meteorological conditions was recorded, through the implementation of a portable meteorological station, which was located within the premises.

Table No. 5.83 Weather conditions during air quality monitoring

Day	Date	Weather (*)	Wind speed (m / s)	Predominant direction of the wind	Relative humidity	Observations
1	24/09/09	S	3,8	S	63%	Sunny day with strong and variable winds.
2	25/09/09	S	2,9	N	78%	Sunny day with variable wind.
3	26/09/09	S	2,0	NE	78%	Sunny day with a little wind.
4	27/09/09	S - LL	1,5	N	78%	Sunny day with heavy rain in the afternoon.
5	28/09/09	S - LL	1,0	SE	78%	Heavy rains in the morning, sunny afternoon.
6	29/09/09	S	0,8	SE	78%	Sunny day with little wind, crossing boats.
7	30/09/09	S - LL	0,8	SE	78%	Sunny day with little wind, heavy rain in the afternoon.
8	01/10/09	S - LL	1,1	SE	78%	Boat crossing, sunny day with little wind, constant boat crossing, heavy rains in the afternoon
9	02/10/09	S - LL	1,3	SE	78%	Sunny day, constant boat crossing, heavy rains in the afternoon.
10	03/10/09	S - LL	1,1	SE	78%	Sunny day, constant boat crossing, rains at night.

[266] Ibíd.

(*) Sunny weather (S) or rainy weather (LL).

Source: ACS. Op. Cit.

The prevailing wind direction was in line with what was expected for this time of year (south, southeast and southwest).

- Results:

Below are the results obtained in the monitoring conducted in the campaign carried out in 2009 by the company Air Clean Systems S.A. (ACS S.A.).

❖ **Suspended particles (TSP y PM_{10}):**

During the 10 days of monitoring, low levels of suspended particles were registered and broad compliance with the permissible limits established by Resolution 610 of 2010[267] of the Ministry of Environment, Housing and Territorial Development, now Ministry of Environment and Sustainable Development was recorded.

According to the results, it can be evidenced in Table No. 5.92 that there were average low TSP concentrations in compliance with the aforementioned regulations, which varied for days with minimum values of 6.07 µg / m³ and an average for the values in days maximum of 19.47 µg / m³.

Table No. 5.84 Summary of TSP monitoring in immission air

stations	Geometric mean (µg / m³)	Minimum value		Maximum value		Permissible limit (µg / m³)
		µg/m³	Day	µg/m³	Day	
1	8,5	5,2	25-26/09/2009	20,6	29-30/09/2009	Annual: 100 24 h: 300
2	12,7	8,2	02-03/10/2009	19,0	27-28/09/2009	
3	7,6	4,8	02-03/09/2009	18,8	25-26/09/2009	

A 25°C y 101,325 kPa.
Source: ARAÚJO IBARRA & ASOCIADOS S.A, 2010[268].

Likewise, the PM10 concentrations complied with the environmental regulations, which did not exceed the permissible limits of immission with arithmetic averages between 4.4 and 9.6 µg / m³ (see Table No. 5.93).

Table No. 5.85 Summary of PM10 monitoring in immission air

stations	Geometric mean (µg / m³)	Minimum value		Maximum value		Permissible limit (µg / m³)
		µg/m³	Day	µg/m³	Day	

[267] Ibíd.
[268] PUERTO BAHÍA COLOMBIA DE URABA S.A. and ARAÚJO IBARRA & ASOCIADOS S.A, 2010. Op Cit.

4	4,4	2,6	03-04/10/2009	7,0	29-30/09/2009	Annual: 50 24 h: 150
5	9,6	6,8	29-30/10/2009	13,1	24-25/09/2009	
6	6,2	2,6	30/09-01/10/2009	12,6	24-25/09/2009	

A 25°C y 101,325 kPa.
Source: ARAÚJO IBARRA & ASOCIADOS S.A, 2010[269].

❖ Nitrogen dioxide:

During the 10 days of monitoring, very low levels of nitrogen dioxide were recorded (more than 75% of the data in each station showed values below the limit of detection of the analytical technique used) as presented in Table No. 5.94. Therefore, a broad compliance with the permissible limits established by Resolution 610 of 2010[270] of the Ministry of Environment, Housing and Territorial Development now Ministry of Environment and Sustainable Development.

Table No. 5.86 Summary of NO2 monitoring in immission air

stations	Geometric mean (µg / m³)	Maximum value		Permissible limit (µg / m³)
		µg/m³	Day	
1	<0,017	0,09	24-25/09/2009	Annual: 100 24 h: 150 1 h: 200
2	<0,017	0,11	02-03/10/2009	
3	<0,017	0,16	02-03/10/2009	

A 25°C y 101,325 kPa.
Source: ARAÚJO IBARRA & ASOCIADOS S.A, 2010.[271].

❖ Sulfur dioxide:

During the 10 days of monitoring, very low levels of sulfur dioxide were recorded (more than 75% of the data in each station showed values below the limit of detection of the analytical technique used) as presented in Table No. 5.95. Therefore, a broad compliance with the permissible limits established by Resolution 610 of 2010[272] of the Ministry of Environment, Housing and Territorial Development now Ministry of Environment and Sustainable Development.

[269] Ibíd.
[270] COLOMBIA. MINISTERIO DE VIVIENDA, AMBIENTE Y DESARROLLO TERRITORIAL. Resolution 610 (March 24, 20101). Op Cit.
[271] Ibíd.
[272] Ibíd.

Table No. 5.87 Summary of SO2 monitoring in immission air

stations	Minimum value (µg/m³)	Maximum value		Permissible limit (µg / m³)
		µg/m³	Day	
1	<0,44	24,44	26-27/09/2009	Annual: 80 24 h: 250 3 h: 750
2	<0,44	17,51	26-27/09/2009	
3	<0,44	11,24	02-03/10/2009	

A 25°C y 101,325 kPa.
Source: ARAÚJO IBARRA & ASOCIADOS S.A, 2010.[273].
.

❖ Carbon monoxide:

During the 10 days of monitoring, low levels of carbon monoxide were recorded (see Table No. 5.96) and broad compliance with the permissible limits established by Resolution 610 of 2010 of the Ministry of Environment, Housing and Territorial Development was recorded, although the levels observed reveal contributions of local anthropic activities, when compared with the average levels reported by ATSDR in the Northern and Southern Hemispheres (respectively 0.12 and 0.04 ppm)[274].

Table No. 5.88 Summary of CO monitoring in immission air

stations	Average (ppm)	Minimum value (ppm)	Maximum value (ppm)	Permissible limit (µg / m³)
1	2,58	2,25	2,92	8 h: 8,8 1 h: 35
2	2,56	2,25	2,77	
3	2,56	2,21	2,78	

Source: ARAÚJO IBARRA & ASOCIADOS S.A, 2010.[275].

- Modeling of air quality during the operation of the viaduct

In order to evaluate the environmental emissions generated by the operation of the viaduct for the transit of vehicles that carry the cargo export and import type unloaded in the Onshore Terminal and Water Terminal of Puerto Bahía Colombia from Urabá SA to the yards and vice versa , a modeling of this scenario was performed to identify the contribution levels of emissions for primary criteria pollutants; PM10, CO, NOx y SO_2, which was presented and approved in the ordinary course of the licensed activity for the construction of a viaduct as a connection

[273] Ibíd.
[274] USA. AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY (ATSDR). Toxicological profile for carbon monoxide [on line]. Draft for comments (until February 26, 2010). September 2009. 310 pages (plus annexes). Available at http://www.atsdr.cdc.gov/toxprofiles/tp201.pdf [quoted on January 12, 2010]. Page 203.
[275] COLOMBIA. MINISTERIO DE VIVIENDA, AMBIENTE Y DESARROLLO TERRITORIAL. Resolution 610 (march, 24, 20101). Op Cit.

between the dock and the harbor terminal through the file ANLA 2015008528-1-000 of February 20, 2015.

For the modeling of the future scenario of the operation of the viaduct, it was done in the AERMOD view modeling software, approved by the Environmental Protection Agency, which determines where pollutants are directed, and which maximum concentrations can reach. It is at these points where the air quality stations should theoretically be located to record the maximum concentrations of the area, as well as determine the receivers that could be affected.

- **Required information**

Terrain Elevations

The area where the project is located corresponds to flat terrain, so it was not necessary to introduce the land elevations of the modeled area. However, the topography of the land was downloaded using the base maps that the software has.

Receivers mesh

For the calculation of the concentrations a uniform grid of receptors was defined that covers radios at different distances until reaching approximately 3000 meters.

Buildings

For the case of the sources of area or volume, as is the case of this project, the effect of the buildings is not considered.

Meteorological Information

The meteorological information to feed the model was obtained with Lakes Environmental and corresponds to data from the meteorological station located in the study area, corresponding to the whole year 2013.

The meteorological data required by any air quality study are:

- Number of wind speed categories.
- Number of stability categories Pasquill - Gifford.
- Number of wind direction categories.

- Vector of accumulated frequency of occurrence of speed and direction of winds for each stability category.
- Environmental temperature vector as a function of the stability category.
- Vector of mixing heights as a function of the stability category, wind direction and station.
- Vector of the average value of each speed category.

Wind Speed

The wind is the air in movement and is presented by differences in pressure, density and other atmospheric characteristics. The measure of the wind is the horizontal component of the movement of the air, this vector has two components: direction and speed. Colombia stands out in an area known as inter-tropical calm, with low-speed winds.

Both in the speed measurements and in the direction of winds it is important to consider the local factors, such as the presence of sea, mountains, urban barriers that influence on the details of the movement of the air.

Figure No. 5.249 and Figure No. 5.250 show the graphical representation of the behavior of the winds according to the meteorological data of the area. The rose of winds is obtained through the complementary software AERMET, entering the information provided by Lakes Environmental

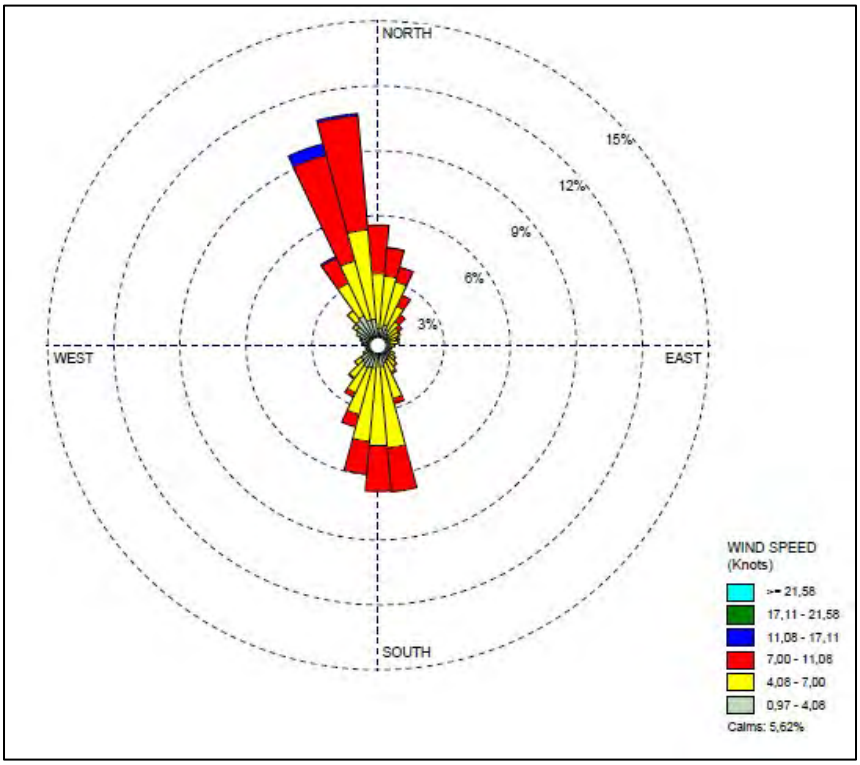


Figure No. 5.229 Winds rose, study area Apartado Colombia
Source: AG Consultores Ambientales S.A.S., 2015

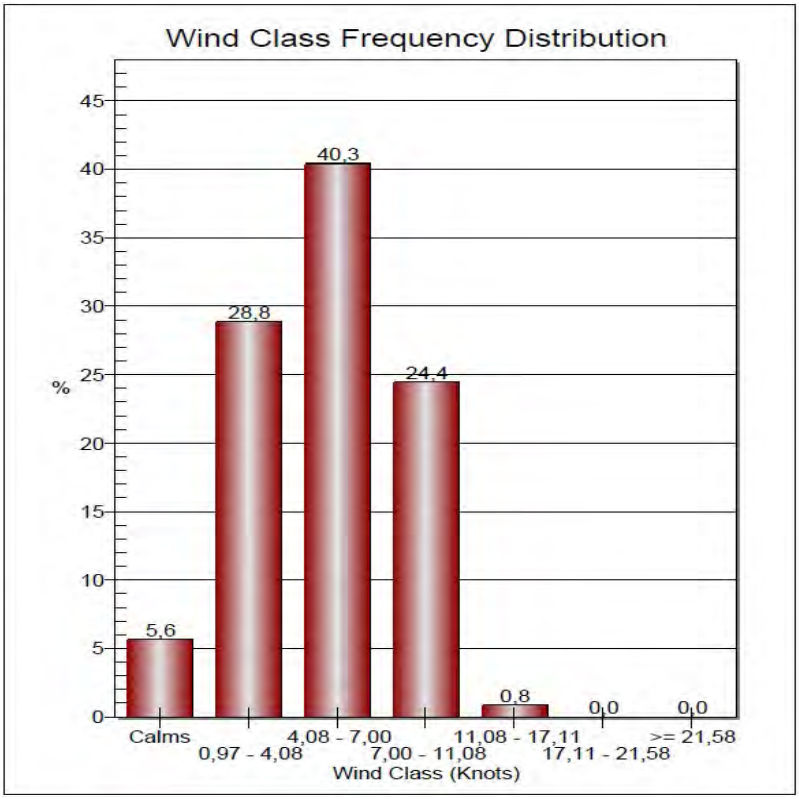


Figure No. 5.230 Frequency distribution of wind classes
Source: AG Consultores Ambientales S.A.S., 2015

Atmospheric Stability

The atmosphere is a continuous and dynamic system where stability changes constantly according to the time of day, the presence of clouds, the type of winds, the surface temperature and the concentration and type of pollutants. In practice, infinite atmospheric situations can be presented; In order to give them an operational treatment, a series of classes or categories are established according to the operative treatment proposed by Pasquill-Guifford (1961) of the Office of Meteorology of Great Britain.

Stabilities are named like this:

A = 1 = Extremely unstable

B = 2 = Unstable

C = 3 = Slightly unstable

D = 4= Neutral

E = 5 = Slightly stable

F = 6 = Moderately stable

Table No. 5.97 classifies the stabilities given by Pasquill-Guifford, according to wind speed, insolation and cloudiness.

Table No. 5.97 Classification of the Stability of the Atmosphere according to Pasquill - Guifford

Wind speed m / s	Day (insolation)			Night (cloudiness)	
	Strong	moderate	Soft	>4/8	<4/8
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Source: AG Consultores Ambientales S.A.S., 2015

Relative Humidity and Solar Brightness

The relative humidity is the ratio between the amount of water vapor in the unsaturated air and the amount of water vapor that the air would admit if it were saturated for a given temperature, the relative humidity is a function of the air temperature.

The solar brightness measurements are made through the heliograph instrument that records the hours of insolation.

AERMET's Feeding Data

The base meteorological information to be pre-processed by the AERMET model, was obtained directly with Lakes Environmental, two files are obtained: a) Hourly Surface Data (file with extension * .sam) and, b) Upper Air Data (file with extension * .ua).

The files were ordered with the following label:

Order #:	MET146264
Ordered by:	Gustavo Gutierrez
Company:	AG Consultores Ambientales SAS
Met Data Type:	AERMET-Ready (Surface & Upper Air Data)
Start-End Date:	Jan 01, 2013 - Dec 31, 2013
Latitude:	7.920556 N
Longitude:	76.736389 W
Datum:	WGS 84
Site Time Zone:	UTC/GMT UTC - 5 hour(s)
Closest City & Country:	apartado - Colombia

Calculated Pseudo Met Station Parameters:

Anemometer Height:	14 m
Station Base Elevation:	25 m
Upper Air Adjustment:	+5 hour(s)

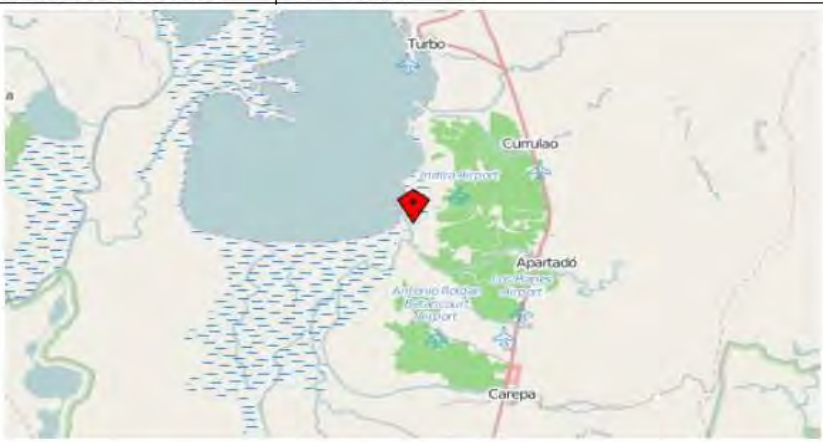


Figure No. 5.231 Information of the meteorological data available for the study area
Source: AG Consultores Ambientales S.A.S., 2015

In Annex 5.1.4 Air and noise quality, the files are presented in * .sam and * .ua formats, which were obtained and with which the meteorological information is processed in the AERMET.

Once this information has been processed, the output data of the AERMET is obtained, with which the AERMOD is fed to perform the modeling. The Aermet output files (* .pfl and * .sfc files) are in Annex 5.1.4 Air and noise quality.

❖ Modeling Configuration

Source characteristics

The viaduct was modeled as an area source and its location, width, total length and base height were fed, as well as the emission of each of the pollutants, in g / s.

The modeling parameters were: Particulate Material less than 10 microns (PM10), Nitrogen Oxides (NOx), Sulfur Dioxide (SO2) and Carbon Monoxide (CO).

These pollutants are included within the so-called criteria pollutants due to the repercussions that they cause on human health and that mainly affect the respiratory tract, lungs and cause headaches and malaise when their concentrations are at such level that they can affect sensitive groups such as children and the elderly.

In Table No. 5.90, the maximum permissible levels established in the Colombian regulations Resolution 610 of 2010 were presented[276].

The potential atmospheric emissions correspond to those generated by the vehicles that will pass through the viaduct. According to the document "Conceptual engineering for port designs on water, viaduct, bridge and onshore port of the Puerto Bahía Colombia project in Urabá S.A, an estimated traffic of 40 vehicles per hour is estimated.

In order to assess the impact of vehicular traffic, emissions are estimated based on the emission factors: Road Transport Emission Factors: 2011 NAEI March 2013 (National atmospheric emissions inventory) of the United Kingdom.

Table No. 5.98 Emission factors for hot exhaust pipes, by vehicle and road type only.

Hot exhaust only		g/km	g/km	g/km	g/km
		NOx	PM10	CO	SO_2
Diesel cars	/ urban roads	0,612	0,020	0,127	0,001

Source: RoadtransportEFs_NAEI11_v1.xls Author: Helen Venfield NAEI Ref: ED56186505 Date:22/03/2013 National atmospheric emissions inventory.

For the calculation, an average vehicle flow of 40 truck trips / hour was considered, for a daily flow of 960 vehicle trips / day.

[276] COLOMBIA. MINISTERIO DE VIVIENDA, AMBIENTE Y DESARROLLO TERRITORIAL now, MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE. Resolution 610 (March 24, 20101). Op Cit

The calculation of the output flow of the pollutants in g / s was made using the calculation aids of the Software, considering the traffic flow and the characteristics of the road. See Table No. 5.98.

The width of the viaduct road is 9 m, paved, with a vehicle traffic equivalent to 40 vehicles per hour and 960 vehicles per day, the speed of the vehicles is estimated at 40 km / h as average.

Table No. 5.99 Concentration of pollutants entered into the modeling

g/s	g/s	g/s	g/s
NOx	**PM10**	**CO**	**SO2**
0,0272	0,00089	0,056	0,00044

Source: AG Consultores Ambientales S.A.S., 2015

Figure No. 5.252 shows the plan of the port terminal and the viaduct through which the cargo vehicles will pass.

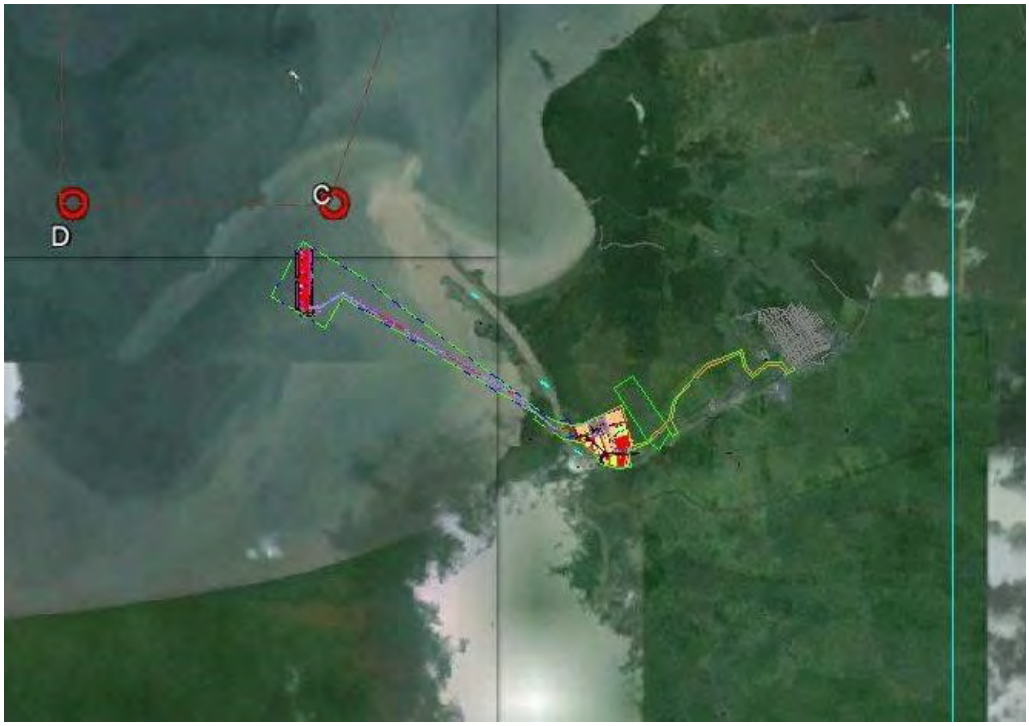


Figure No. 5.232 Project plan, viaduct Puerto Bahía Colombia De Urabá S.A.
Source: AG Consultores Ambientales S.A.S., 2015

Averaging periods

In order to compare the results of the model, runs for each pollutant were made with the averaging periods established by resolution 610 of the 2010 MAVDT today MADS, which are shown in Table No. 5.100.

Table No. 5.89 Averaging periods of pollutants during modeling

Parameter	Period
PM10	24 hours
NOx	24 hours
SO_2	24 hours
CO	8 hours

Source: AG Consultores Ambientales S.A.S., 2015

- **Modeling results**

As a result of the execution of the model, a graphical modeling is obtained that is shown in the annexed files by isopleth curves obtained for all pollutants and modeled averaging period. The running time of each run was 4 hours for each pollutant.

Next, the graphs of results generated by the AERMOD view are presented, in which the distribution of the concentrations generated by the modeled emission source is displayed. The output documents in PDF format can be found in Annex 5.1.4 Air and noise quality.

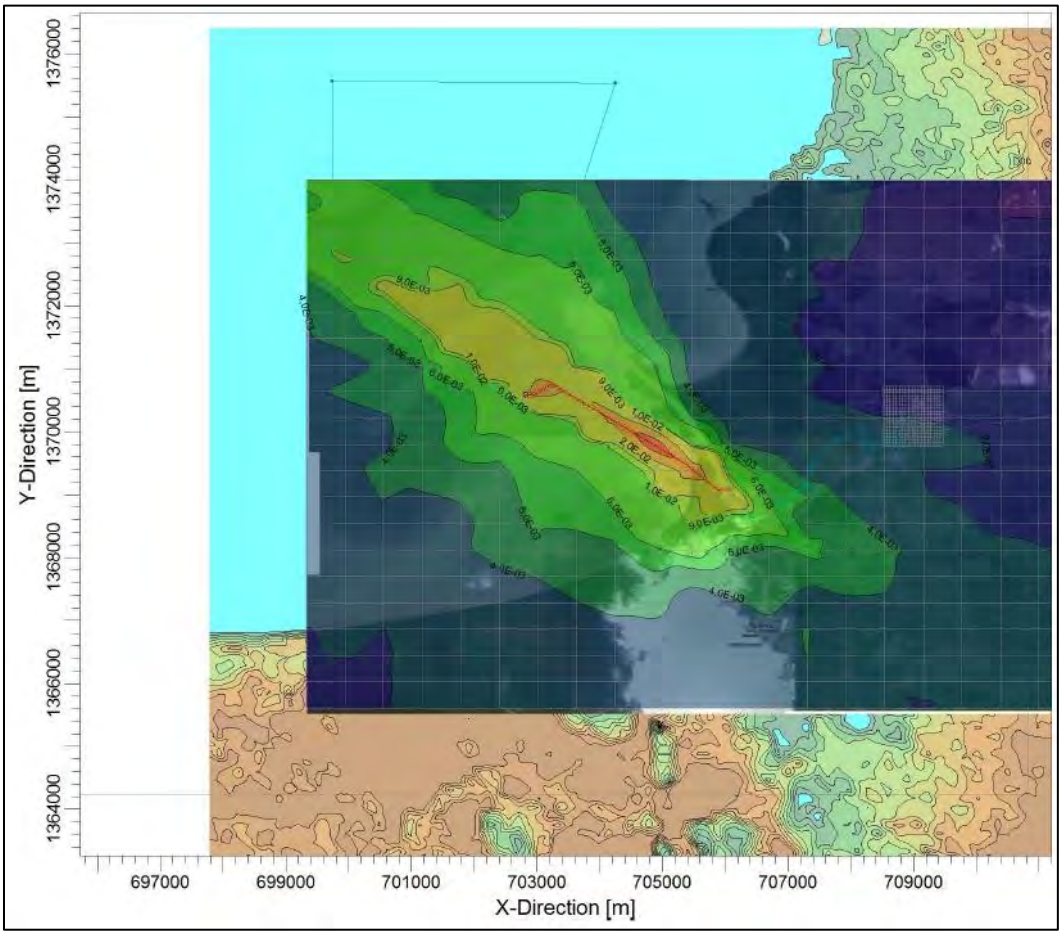


Figure No. 5.233 Particulate material modeling result, PM10 in the study area.
Source: AG Consultores Ambientales S.A.S., 2015

The particulate material distribution smaller than 10 microns PM10, which is presented in Figure No. 5.253, shows a dispersion plume parallel to the viaduct that is the source of emission. The highest concentrations are found within the first 400 meters on each side of the road, within this distance there are concentrations between 0.02 µg / m3 to 0.009 µg / m3. With respect to the possible receivers, an approximate contribution of 0.002 µg / m3 is observed on the population of Nueva Colonia, which is the nearest population, located approximately 3 km from the viaduct, this contribution corresponds to 0.002% of the maximum permissible limit established in the standard (100 µg / m3).

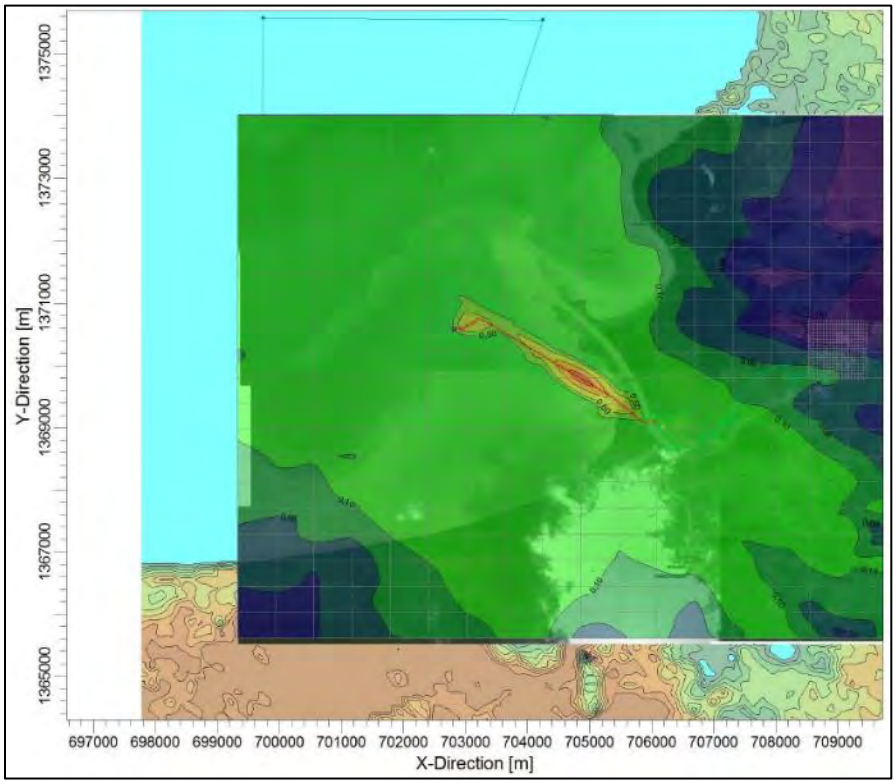


Figure No. 5.234 Nitrogen Oxides modeling result, NOx in the study area
Source: AG Consultores Ambientales S.A.S., 2015

The nitrogen oxides distribution presented in Figure No. 5.254, shows that the highest concentrations are found in the first 200 meters on each side of the road, distance at which the concentration is 0.50 µg / m3 on average. With respect to the possible receivers, a contribution of 0.08 to 0.06 µg / m3 is observed on the population of Nueva Colonia, this contribution corresponds to 0.05% of the maximum permissible limit established in the standard (150 µg). / m3).

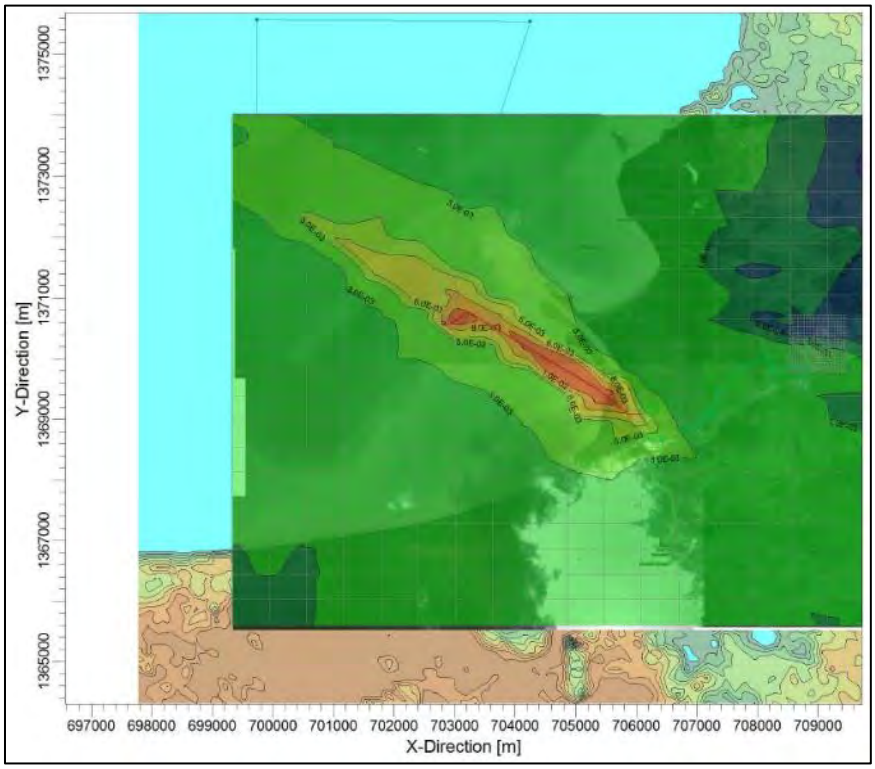


Figure No. 5.235 Sulfur Dioxide modeling result, SO2 in the study area
Source: AG Consultores Ambientales S.A.S., 2015

The sulfur dioxide SO2 distribution presented in Figure No. 5.255, shows that the highest concentrations are up to 600 meters on each side of the road, where concentrations are between 0.01 µg / m3 to 0.005 µg / m3. The dispersion plume follows a pattern parallel to the direction of the road, with a tendency mostly to the northwest. With respect to the possible receivers, a contribution of between 0.001 to 0.0008 µg / m3 is observed over the population of Nueva Colonia, the nearest population, contribution corresponding to 0.0004% of the maximum permissible limit established in the standard (250 µg / m3).

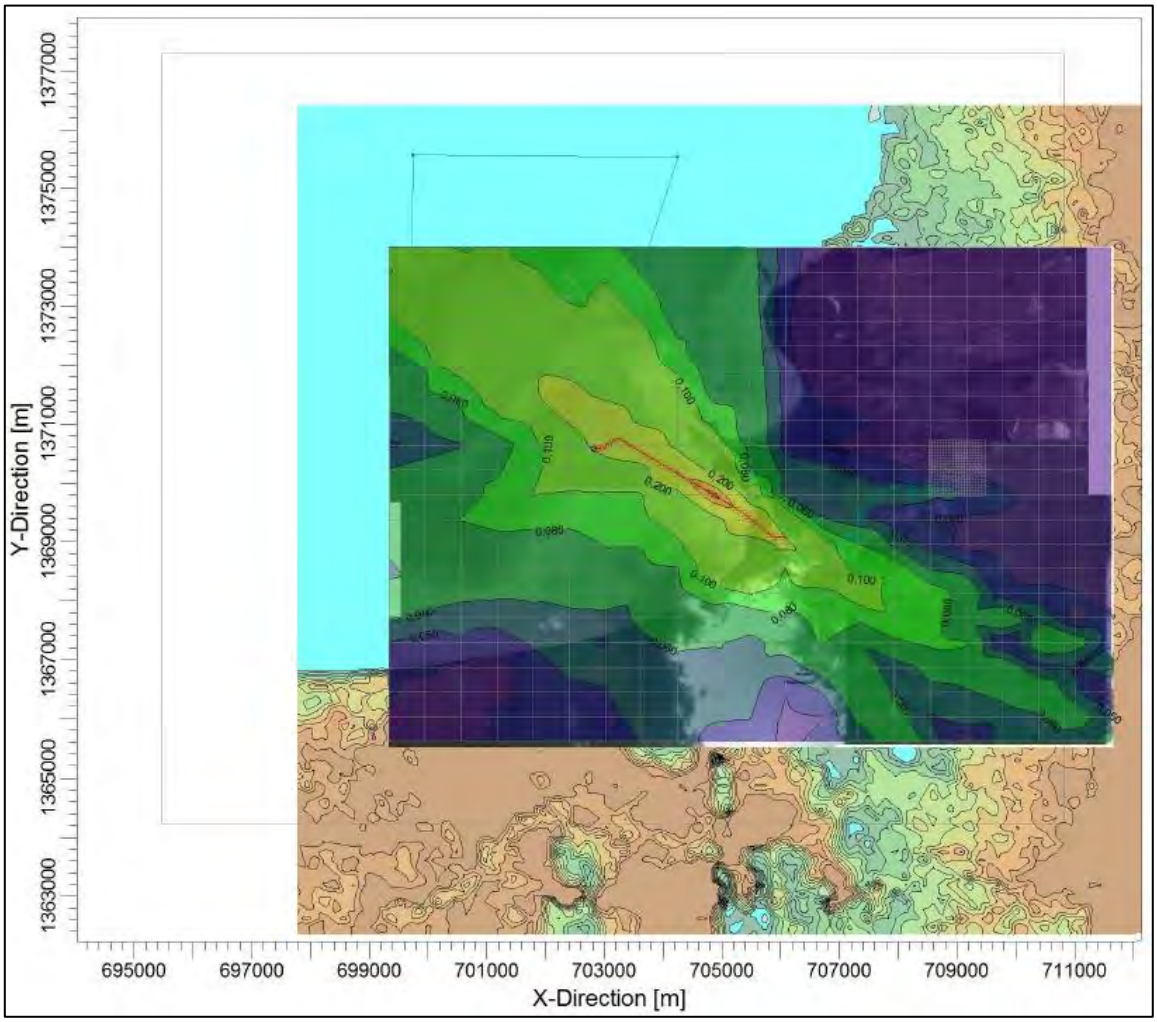


Figure No. 5.236 Carbon Monoxide modeling result, CO in the study area.
Source: AG Consultores Ambientales S.A.S., 2015

The carbon monoxide CO distribution, presented in Figure No. 5.256, shows that the highest concentrations are in the first 400 meters on each side of the road, the highest concentrations in this area are 0.20 µg / m3 in average. With respect to the possible receivers, a maximum contribution of 0.050 µg / m3 is observed over the population of Nueva Colonia. This contribution corresponds to 0.0005% of the maximum permissible limit established in the standard (10,000 µg / m3).

Maximum Concentrations

Table No. 5.101 shows the maximum concentrations obtained in the modeling of the project. It is observed that the pollutants that presents a higher concentration are the oxides of nitrogen, with a maximum concentration of 1.1691 g / m3. The other pollutants presented values below 1 µg / m3 as shown in the table.

Table No. 5.101 Maximum concentrations obtained in modeling

POLLUTANT	AVERAGING PERIOD	NORMATIVE LIMIT (µg / m3)	CONCENTRATION (µg/m^3)	STANDARD %
PM10	24 hours	100	0,03799	0,037
NOx	24 hours	150	1,16091	0,774
SO_2	24 hours	250	0,01878	0,007
CO	8 hours	10.000	0,54149	0,005

Source: AG Consultores Ambientales S.A.S., 2015

Total Concentrations

For the calculation of the total concentrations, the maximum concentrations obtained in the EIA air quality studies of the project were used. These values were added to the maximum values calculated by modeling, obtaining the results shown in Table No. 5.102. This calculation implicitly assumes that the stations were located in such a way as to measure background concentrations.

In this way the maximum expected concentrations during the operation of the port are obtained, with the construction of the viaduct.

From these tables it can be deduced that the expected increase of the concentration is low, being higher for nitrogen oxides which represents 966% of the current emissions.

Table No. 5.90 Total concentrations of the area

POLLUTANT	AVERAGING PERIOD	ACTUAL (µg/m^3)	MODELED (µg / m3)	TOTAL (µg/m^3)	INCREASE
PM10	24 hours	10,9	0,04	10,94	0,37%
NOx	24 hours	0,12	1,16	1.28	966%
SO_2	24 hours	17,73	0,02	17,75	0,11%

CO	8 hours	2,57	0,54	3.11	21%

Source: AG Consultores Ambientales S.A.S., 2015

❖ Conclusions

The modeling performed shows that the contribution of the criteria pollutants; PM10, SO2, NOx and CO for the operation of the viaduct indicates relatively low values, below the maximum permissible limits established in Resolution 610 of 2010 of the MAVDT today MADS.

The contribution of the levels of pollution provided by the operation of the viaduct, added to the values obtained in the baseline for the current conditions (without project), remains below the maximum permissible limits.

The maximum value of PM10 obtained by the operation of the viaduct was 0.04 µg / m3, equivalent to an increase of 0.37%, with respect to the maximum average values obtained in the baseline for a period of 24 hours (10 , 9 µg / m3).

The maximum value of CO obtained by the operation of the viaduct was 0.54 µg / m3, equivalent to an increase of 21%, with respect to the maximum average values obtained in the baseline for a period of 8 hours (2.57 µg / m3).

The maximum value of SO2 obtained by the operation of the viaduct was 0.02 µg / m3, equivalent to an increase of 0.11%, with respect to the maximum average values obtained in the baseline for a period of 24 hours (250µg). / m3).

The maximum value of NOx obtained by the operation of the viaduct was 1.16 µg / m3, equivalent to an increase of 966%, with respect to the maximum average values obtained in the baseline (0.12 µg / m3). Despite the notable increase in this parameter, the results still present values below the permissible limits, for a period of 24 hours (150 µg / m3).

The vehicular traffic to circulate through the new viaduct of the Puerto Bahía Colombia project of Urabá S.A, will generate minimal, insignificant contributions of the modeled polluted criteria; particulate material PM10, SO2, NOx and CO.

- *Noise*

To determine the levels of environmental noise, a monitoring was made in the area of influence of the project, which was in charge of the company SGS Colombia SAS, for which four (4) representative points were selected, which were monitored on July 10 (business day) and July 12 (non-business day) of the year 2015. The location of these points is shown below in Figure No. 5.257 and in Table No. 5.103.

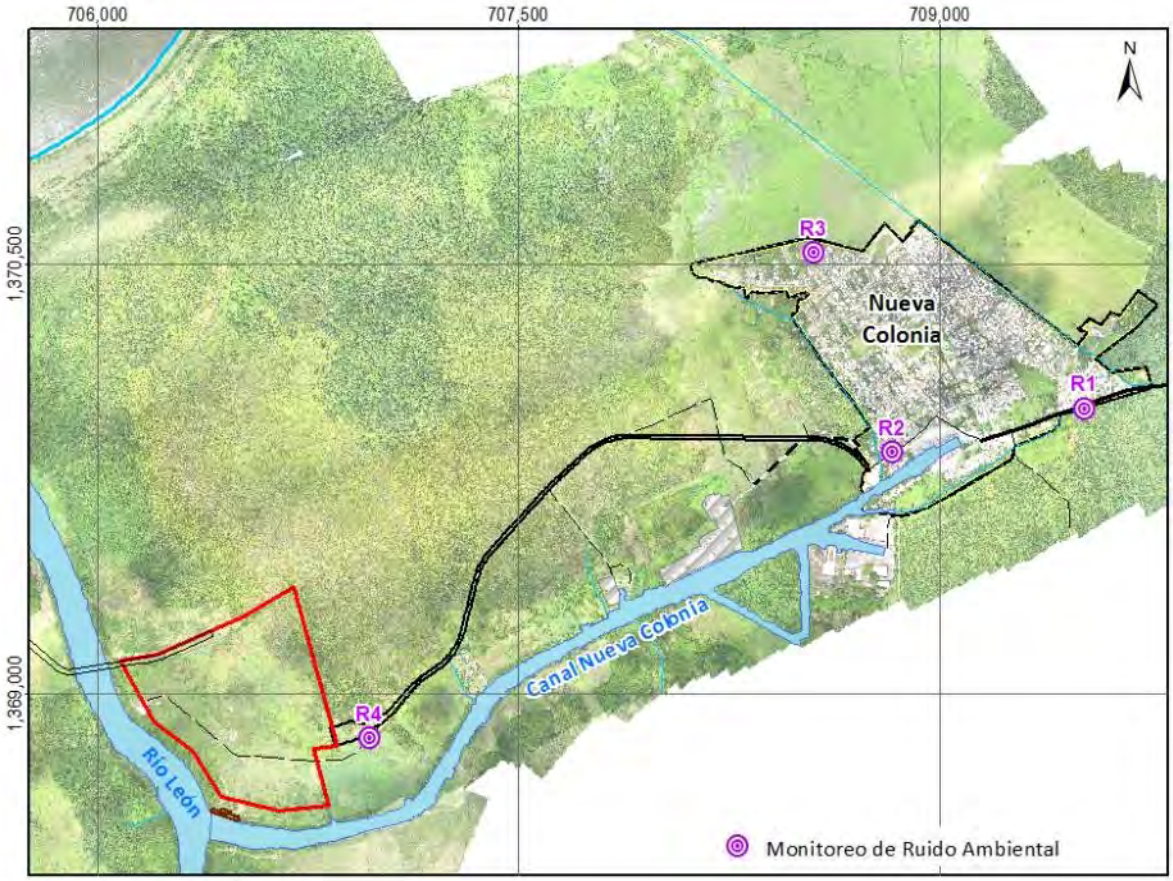


Figure No. 5.237 Location of environmental noise monitoring points
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

Table No. 5.91 Coordinates of environmental noise monitoring points

ID	FLAT COORDINATES MAGNA SIRGAS Origin BOGOTÁ	
	EAST	NORTH
R1	709.518,96	1.369.996,53
R2	708.833,52	1.369.842,90
R3	708.553,10	1.370.542,73
R4	706.969,86	1.368.841,19

Source: Aqua & Terra Consultores Asociados S.A.S, 2015

The equipment used for the measurement of noise emission was an automatic integrating sound level meter and a verification piston CASELLA brand and to measure the atmospheric parameters a meteorological station was used, which have their calibration certificates in Annex 5.1.4 Air and noise quality.

For the verification of the correct operation of the sound level meter, an Acoustic Calibrator with type 1 precision was used for sound level meters with an output frequency of 1000 Hz and 114 dB

- Description of monitoring points

Point R1: Monitoring point located on the Nueva Colonia road to the Rio Grande district that connects with the national route 62, at the entrance to the Nueva Colonia district. On the right side of the road are houses and on the left side banana crops, see Photo No. 5.29.

Photograph No. 5.29 Monitoring point R1
Source: SGS Colombia, July 2015

Point R2: This point was located in the urban center of the Nueva Colonia district on the outskirts of the district, near the main road that leads from the Nueva Colonia district to the port project. The measurements were made on an unpaved street and the area surrounding the monitoring point was surrounded by houses and shrub vegetation. See Photograph No. 5.30.

Photograph No. 5.30 Monitoring Point – R2
Source: SGS Colombia, July 2015

Point R3: Monitoring point with low population density, located northwest of the district of Nueva Colonia with presence of shrub and arboreal vegetation and on an unpaved street. See Photograph No. 5.31.

Photograph No. 5.31 Monitoring Point - R3
Source: SGS Colombia, July 2015

Point R4: Monitoring point located on an unpaved road, approximately two kilometers from the Nueva Colonia district in an east-west direction. The sides of the road correspond to paddocks for livestock. See Photograph No. 5.32.

Photograph No. 5.32 Monitoring Point – R4
Source: SGS Colombia, July 2015

- Atmospheric conditions in the area of influence

In the days of the environmental noise monitoring, the atmospheric conditions detailed below in Table No. 5.104 were presented.

Table No. 5.92 Weather conditions

Monitoring date	Average temperature (° C)	Maximum temperature (° C)	Minimum temperature (° C)	Atmospheric pressure at sea level (mmHg)	Average relative humidity (%)	Total precipitation of rain and / or melted snow (mm)	Average wind speed (Km / h)	Sustained maximum wind speed (Km / h)
Business Day 10/07/2015	28	37,2	23,8	759,9	84	0	0,5	8,5
Non-working day 07/12/2015	27	33,4	24,2	763,6	86	0	1,2	14,8

Source: SGS COLOMBIA S.A.S., Julio 2015

- Comparison with the standard

The monitoring was carried out on day and night hours, on working and non-working days, and the results of the measurements were compared with the maximum permissible standards of the sector. In accordance with the characteristics of each monitoring point, it was classified in one of the subsectors defined by Resolution 627 of 2006[277] as shown in Table No. 5.105.

Table No. 5.105 Maximum Permissible Standards for ambient noise levels, expressed in DB decibels (A)

Monitoring point	**Sector**	**Subsector**	**Maximum permissible standards of ambient noise levels in dB (A)**	
			Day	**Night**
R1 and R2	Sector C. Restricted Intermediate Noise	Areas with commercial permitted uses, such as shopping centers, warehouses, commercial premises and facilities, workshops for automotive and industrial mechanics, sports and recreational centers, gyms, restaurants, bars, taverns, casinos.	70	55
R3	Sector B. Tranquility and Moderate Noise	Residential areas or exclusively destined for housing development, hotels and lodgings.	65	50
R4	Sector D. Suburban or Rural of Tranquility and Moderate Noise.	Rural inhabited destined to agricultural exploitation.	55	45

Source: Resolution627 of 2006[278]

[277] COLOMBIA. MINISTRY OF ENVIRONMENT, HOUSING AND SUSTAINABLE DEVELOPMENT. Resolution 627 (April, 07, 2006). By which the national standard of emission of noise and environmental noise is established. . Bogotá D.C., 2006
[278] Ibíd.

- Obtained Results

A consolidation of the measurements and adjustments obtained in each of the points in the respective addresses is presented for the working day in Table No. 5.106 and for the non-working day in Table No. 5.107

Table No. 5.106 Environmental noise measurement results and corrections, working day

Measurement Point	Address	LAeq	Lmax	Lmin	L90	LAI	Corrections				LAeq Corr
							KT	KI	KR	KS	
R1	Diurnal										
	North	69,1	85,1	59,0	61,5	71,1	0	0	0	0	69,1
	East	67,7	83,4	57,1	61,0	70,3	0	0	0	0	67,7
	South	63,3	79,5	53,5	55,0	65,6	0	0	0	0	63,3
	West	66,2	83,7	58,6	61,0	69,4	0	3	0	0	69,2
	Vertical	64,4	86,1	57,5	60,0	68,5	0	3	0	0	67,4
	Nocturnal										
	North	67,1	83,5	48,0	53,0	69,4	0	0	0	0	67,1
	East	68,9	92,6	46,3	51,0	73,7	0	3	0	0	71,9
	South	70,6	88,9	48,7	51,5	72,4	0	0	0	0	70,6
	West	68,2	89,6	45,8	49,0	70,6	0	0	0	0	68,2
	Vertical	69,1	85,4	49,2	52,5	71,0	0	0	0	0	69,1
R2	Diurnal										
	North	62,3	83,2	54,9	57,0	67,0	0	3	0	0	65,3
	East	60,8	77,6	54,4	56,5	65,5	0	3	0	0	63,8
	South	63,6	85,9	54,6	56,5	68,4	0	3	0	0	66,6
	West	63,0	80,6	54,9	56,5	67,3	0	3	0	0	66,0
	Vertical	59,7	77,7	53,2	56,0	64,7	0	3	0	0	62,7
	Nocturnal										
	North	54,6	76,8	43,1	46,5	61,1	0	6	0	0	60,6
	East	63,8	88,1	41,4	48,0	70,3	0	6	0	0	69,8
	South	55,9	72,5	45,3	48,0	60,8	0	3	0	0	58,9
	West	63,8	87,8	42,6	46,0	70,4	0	6	0	0	69,8
	Vertical	53,2	69,8	43,6	47,0	58,7	0	3	0	0	56,2
R3	Diurnal										
	North	50,9	68,3	43,8	46,0	55,3	0	3	0	0	53,9
	East	75,1	77,9	70,3	70,5	75,5	0	0	0	0	75,1

Measurement Point	Address	LAeq	Lmax	Lmin	L90	LAI	Corrections				LAeq Corr
							KT	KI	KR	KS	
	South	51,5	73,0	44,1	46,0	58,1	0	6	0	0	57,5
	West	65,3	70,4	59,6	60,5	65,7	0	0	0	0	65,3
	Vertical	53,4	71,6	44,9	48,5	59,6	0	6	0	0	59,4
	Nocturnal										
	North	56,1	64,0	53,2	54,0	57,0	0	0	0	0	56,1
	East	56,8	66,1	54,8	55,5	57,9	0	0	0	0	56,8
	South	55,7	65,4	53,6	54,0	56,6	0	0	0	0	55,7
	West	56,4	65,9	54,5	55,0	57,5	0	0	0	0	56,4
	Vertical	74,2	78,8	53,2	54,5	74,4	0	0	0	0	74,2
R4	Diurnal										
	North	51,2	59,3	50,6	51,0	52,2	0	0	0	0	51,2
	East	48,7	56,9	47,7	48,5	49,6	0	0	0	0	48,7
	South	50,6	60,0	48,8	50,5	51,3	0	0	0	0	50,6
	West	49,6	63,9	48,0	49,0	50,7	0	0	0	0	49,6
	Vertical	48,7	55,2	47,5	48,0	49,7	0	0	0	0	48,7
	Nocturnal										
	North	54,8	69,0	53,5	54,0	55,7	0	0	0	0	54,8
	East	56,7	72,7	55,6	56,0	58,9	0	0	0	0	56,7
	South	56,2	68,0	55,2	55,5	58,9	0	0	0	0	56,2
	West	59,1	64,8	55,6	56,5	60,8	0	0	0	0	59,1
	Vertical	56,3	62,5	55,1	55,5	58,7	0	0	0	0	56,3

Source: SGS COLOMBIA S.A.S., Julio 2015

Table No. 5.93 Environmental noise measurement results and corrections, non-working day

Measurement Point	Address	LAeq	Lmax	Lmin	L90	LAI	Corrections				LAeq Corr
							KT	KI	KR	KS	
R1	North	64,9	83,6	49,6	53,0	68,5	0	3	0	0	67,9
	East	58,5	73,7	50,9	52,5	61,5	0	0	0	0	58,5
	South	62,4	86,4	48,4	53,0	67,0	0	3	0	0	65,4
	West	63,7	80,4	49,8	54,0	65,7	0	0	0	0	63,7
	Vertical	64,3	83,6	49,8	53,0	68,2	0	3	0	0	67,3
	Nocturnal										
	North	50,5	66,6	46,7	48,0	52,1	0	0	0	0	50,5
	East	55,6	72,0	47,0	48,5	59,4	0	3	0	0	58,6

Measurement Point	Address	LAeq	Lmax	Lmin	L90	LAI	Corrections				LAeq Corr
							KT	KI	KR	KS	
	South	49,3	61,7	47,6	48,0	50,8	0	0	0	0	49,3
	West	55,3	76,2	47,9	48,5	57,4	0	0	0	0	55,3
	Vertical	51,6	70,1	46,7	47,5	53,5	0	0	0	0	51,6
R2	Diurnal										
	North	65,4	82,7	49,3	51,0	66,8	0	0	0	0	65,4
	East	59,9	78,7	52,3	55,0	64,8	0	3	0	0	62,9
	South	61,4	87,0	50,4	53,5	68,5	0	6	0	0	67,4
	West	64,7	86,1	53,9	56,0	70,5	0	3	0	0	67,7
	Vertical	53,7	72,0	48,8	50,5	56,9	0	3	0	0	56,7
	Nocturnal										
	North	53,8	61,4	50,5	52,0	55,5	0	0	0	0	53,8
	East	47,7	55,4	45,2	46,5	49,1	0	0	0	0	47,7
	South	53,1	61,6	48,9	51,5	54,8	0	0	0	0	53,1
	West	50,8	58,0	48,2	49,5	52,3	0	0	0	0	50,8
	Vertical	53,3	60,8	49,7	51,5	54,8	0	0	0	0	53,3
R3	Diurnal										
	North	78,2	91,0	54,9	68,0	82,0	0	3	0	0	81,2
	East	72,9	87,4	52,3	58,5	76,7	0	3	0	0	75,9
	South	76,7	89,6	65,1	62,0	80,3	0	3	0	0	79,7
	West	74,1	87,1	54,7	60,5	77,9	0	3	0	0	77,1
	Vertical	75,9	86,3	53,6	65,5	79,3	0	3	0	0	78,9
	Nocturnal										
	North	53,0	58,6	52,0	52,5	54,4	0	0	0	0	53,0
	East	54,1	57,1	51,9	53,5	55,4	0	0	0	0	54,1
	South	52,7	59,2	51,6	52,0	53,9	0	0	0	0	52,7
	West	53,5	57,0	51,2	53,0	54,8	0	0	0	0	53,5
	Vertical	52,9	59,0	51,8	52,5	54,1	0	0	0	0	52,9
R4	Diurnal										
	North	43,7	56,3	41,6	42,5	44,8	0	0	0	0	43,7
	East	40,8	53,9	38,4	39,5	42,4	0	0	0	0	40,8
	South	44,5	59,4	40,3	43,0	46,8	0	0	0	0	44,5
	West	42,5	61,7	38,6	40,0	47,6	0	3	0	0	45,5
	Vertical	44,1	56,7	41,4	43,0	45,2	0	0	0	0	44,1
	Nocturnal										
	North	54,9	59,5	54,5	54,5	55,4	0	0	0	0	54,9
	East	55,0	58,3	54,4	54,5	55,4	0	0	0	0	55,0
	South	55,0	61,8	54,5	54,5	55,5	0	0	0	0	55,0
	West	54,3	57,4	53,9	54,0	54,8	0	0	0	0	54,3
	Vertical	54,8	57,7	54,2	54,5	55,2	0	0	0	0	54,8

Source: SGS COLOMBIA S.A.S., Julio 2015

The following table shows the consolidated environmental noise results of the monitoring points (R1, R2, R3 and R4) in Table No. 5.108 and Table 5.109, considering that the value that is compared with the standard is the equivalent level of the measurement adjusted to the corrections established by Annex 2 of Resolution 627 of 2006[279] (LAeq Corrected).

Table No. 5.108 Consolidated environmental noise results, monitoring point R1

Measurement point	Date	Measurement time	LAeq corrected dB (A)	Lmax dB (A)	Lmin dB (A)	L90 dB (A)	Limit Res. 627 of 2006 dB (A)	Compliance
R1	Diurnal							
	10/07/2015 working day	19:20 - 20:20	67,8	86,1	53,50	60,2	70	Complies
	12/07/2015 non-working day	09:00 - 10:00	65,6	86,4	48,40	53,1	70	complies
	Nocturnal							
	11/07/2015 Working day	04:50 - 05:50	69,7	92,6	45,8	51,6	55	Does not comply
	12/07/2015 non-working day	04:00 - 05:00	54,5	76,2	46,7	48,1	55	Complies

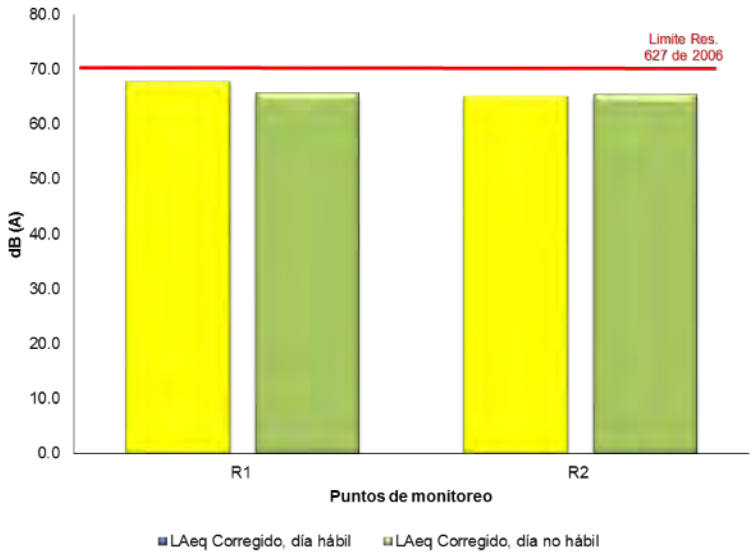
Source: SGS COLOMBIA S.A.S., July 2015

[279] Ibíd

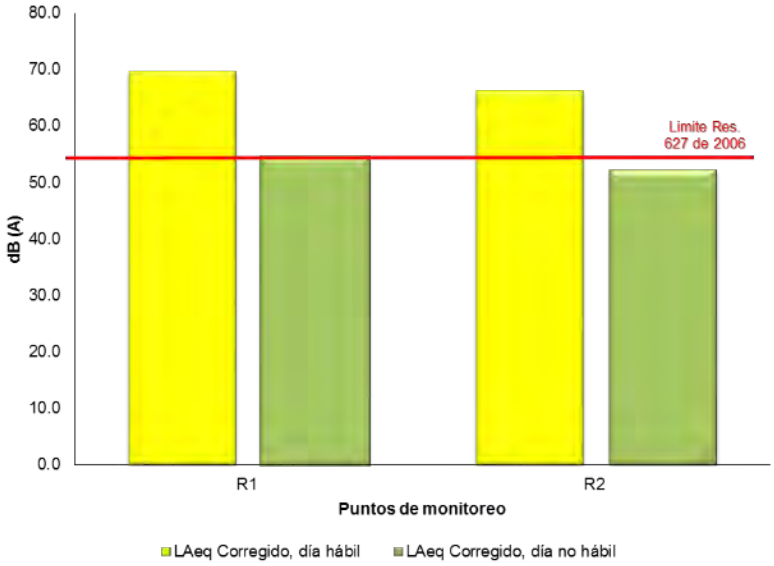
Table No. 5.94 Consolidated environmental noise results, monitoring point R2

Measurement point	Date	Measurement time	LAeq Corrected dB (A)	Lmax dB (A)	Lmin dB (A)	L90 dB (A)	Limit Res. 627 of 2006 dB (A)	Compliance
R2	Diurnal							
	10/07/2015 Working day	16:45 - 17:45	65,1	85,9	53,2	56,5	70	Complies
	12/07/2015 non-working day	11:20 - 12:20	65,4	87,0	48,8	53,7	70	Complies
	Nocturnal							
	11/07/2015 working day	06:00 - 07:00	66,3	88,1	41,4	47,2	55	Does not comply
	12/07/2015 Non-working day	01:30 - 02:30	52,2	61,6	45,2	50,6	55	Complies

Source: SGS COLOMBIA S.A.S., Julio 2015



Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)
Figure No. 5.238 Environmental noise during the day, monitoring points R1 and R2
Source: SGS COLOMBIA S.A.S., July 2015

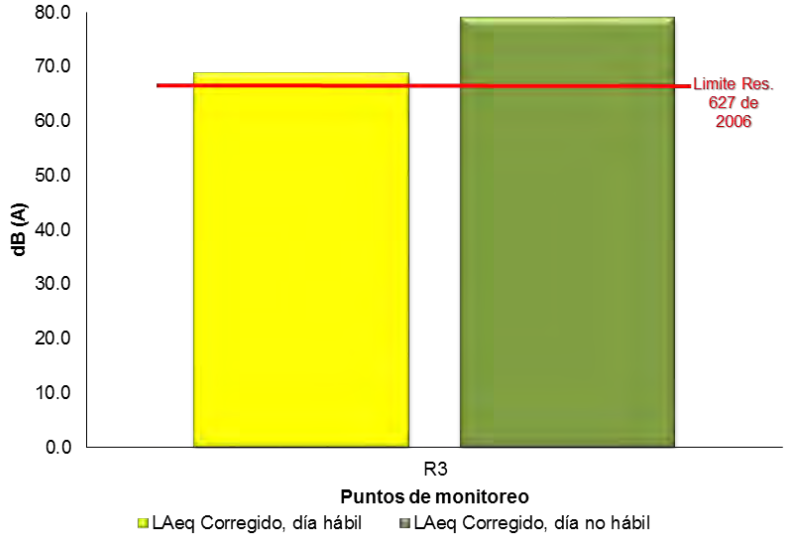


Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)
Figure No. 5.239 Environmental noise at night time, monitoring points R1 and R2
Source: SGS COLOMBIA S.A.S., Julio 2015

Table No. 5.95 Consolidated environmental noise results, monitoring point R3

Measurement point	Date	Measurement time	LAeq Corrected dB (A)	Lmax dB (A)	Lmin dB (A)	L90 dB (A)	Limit Res. 627 of 2006 dB (A)	Compliance
R3	Diurnal							
	10/07/2015 Working day	18:02 - 19:02	68,7	77,9	43,8	64,0	65	Does not comply
	12/07/2015 Non-working day	10:15 - 11:15	79,0	91,0	52,3	64,2	65	Does not comply
	Nocturnal							
	10/07/2015 Working day	21:40 - 22:40	67,5	78,8	53,2	54,6	50	Does not comply
	12/07/2015 Non-working day	02:45 - 03:45	53,3	59,2	51,2	52,7	50	Does not comply

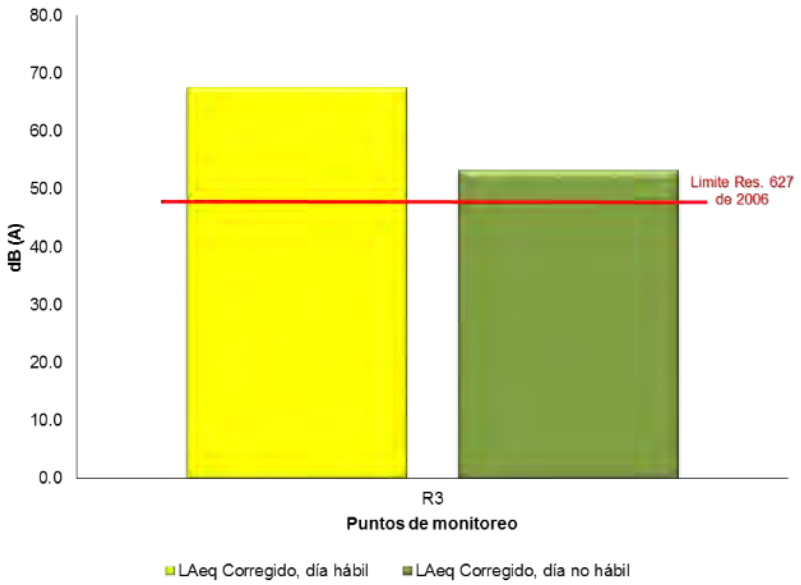
Source: SGS COLOMBIA S.A.S., July 2015



Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)

Figure No. 5.240 Environmental noise during the day, monitoring point R3

Source: SGS COLOMBIA S.A.S., July2015



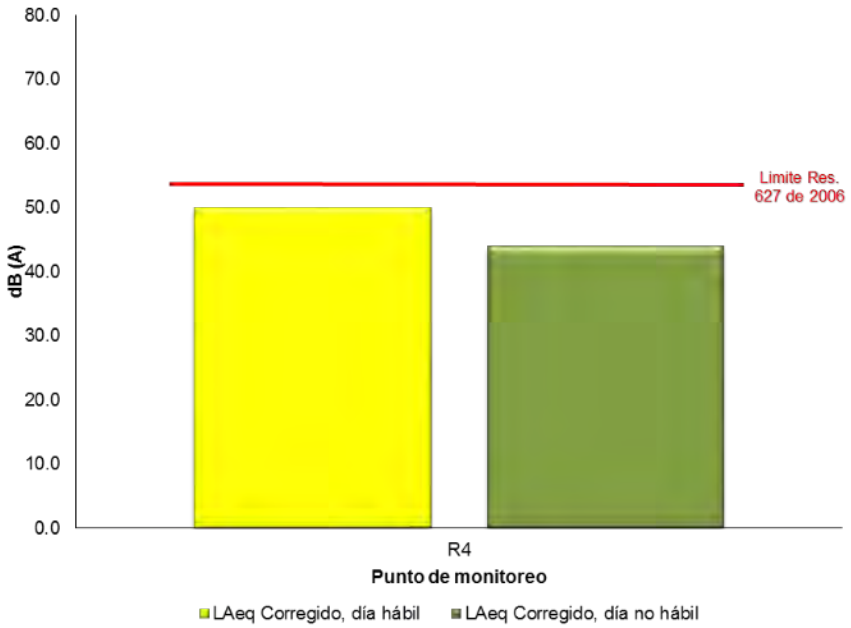
Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)
Figure No. 5.241 Environmental noise at night time, monitoring point R3
Source: SGS COLOMBIA S.A.S., July 2015

Table No. 5.96 Consolidated environmental noise results, monitoring point R4

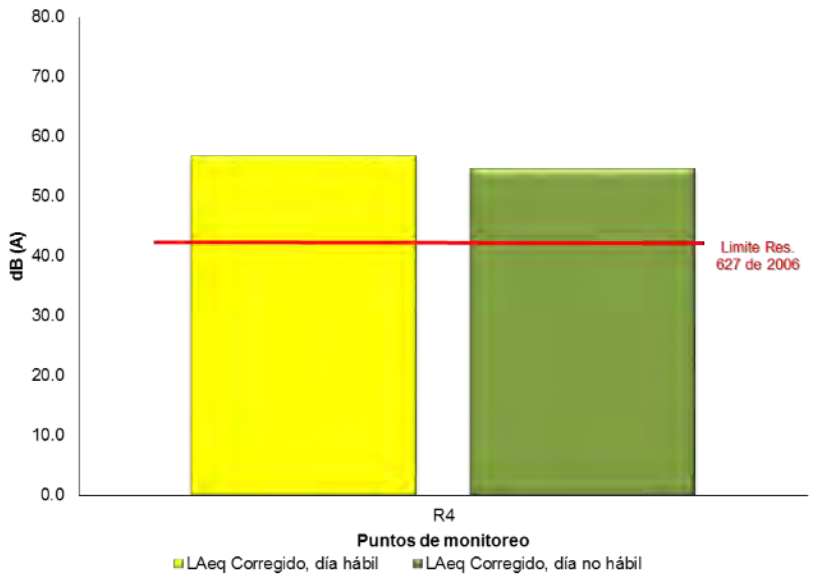
Measurement point	Date	Measurement time	LAeq Corrected dB (A)	Lmax dB (A)	Lmin dB (A)	L90 dB (A)	Limit Res. 627 of 2006 dB (A)	Compliance
R4	Diurnal							
	10/07/2015 Working day	15:15 - 16:15	49,9	63,9	47,5	49,6	55	Complies
	12/07/2015 Non-working day	12:40 - 13:40	44,0	61,7	38,4	41,9	55	Complies
	Nocturnal							
	11/07/2015 Working day	23:00 - 00:00	56,9	72,7	53,5	55,6	45	Does not comply
		00:05 - 01:05	54,8	61,8	53,9	54,4	45	Does not comply

Measurement point	Date	Measurement time	LAeq Corrected dB (A)	Lmax dB (A)	Lmin dB (A)	L90 dB (A)	Limit Res. 627 of 2006 dB (A)	Compliance
	12/07/2015 Non-working day							

Source: SGS COLOMBIA S.A.S., July 2015



Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)
Figure No. 5.242 Environmental noise at night time, monitoring point R4
Source: SGS COLOMBIA S.A.S., July 2015



Monitoring Points----Corrected LAeq(working day)-- Corrected LAeq(non-working day)
Figure No. 5.243 Environmental noise at night time, monitoring point R4
Source: SGS COLOMBIA S.A.S., July 2015

The reports of the samples without processing and the application of the k adjustments in Excel format are found in Annex 5.1.4 Air and noise quality.

- Results Analysis

Monitoring points R1 and R2

- The levels of environmental noise determined during daytime hours, working days and non-business hours, in points R1 and R2, comply with the provisions of Resolution 627 of April 2006[280] for sector C, restricted intermediate noise, sub-sector areas with commercial permitted uses, because it does not exceed the ambient noise level of 70 dB (A).

- The environmental noise levels of the measurements made during the night shift during the working and non-working days, at point R1 exceeds the permissiveness limit, while point R2 complies with the provisions of

[280] Ibíd.

Resolution 627 of 2006[281], for Sector C, subsector areas with commercial permitted uses reporting sound levels above 55 dB (A).

- The results obtained at the R1 monitoring point could be affected by the noises emitted by the mobile sources that travel via Nueva Colonia to the Rio Grande district that communicates with the national route 62, adjacent to the monitoring point.

- At the monitoring points R1 and R2 there was music registered coming from the homes.

Monitoring point R3

- The levels of environmental noise determined during daytime hours, working days and non-working days, at point R3, fail to comply with the provisions of Resolution 627 of April 2006[282] for sector B, tranquility zone and moderate noise, since the values obtained for the equivalent continuous sound level, are higher than the maximum permissible limit of the standard, for environmental noise in this sector (65 dB (A)).

- The environmental noise levels of the measurements made during the night shift during working and non-working days, at point R3, exceed the permissiveness limit established in Resolution 627 of 2006[283], for Sector B, reporting sound levels above 50 dB (A).

- The monitoring point R3 during the day, non-working day, could be affected by the noises coming from the Christian church located a few meters from the monitoring point.

Monitoring point R4

- The levels of environmental noise determined during daytime hours, working days and non-working days, in point R4 comply with the provisions of Resolution 627 of April 2006[284] for sector D. suburban or rural area of tranquility and moderate noise.

- The environmental noise levels of the measurements made during the night shift during working and non-working days, at point R4, exceed the

[281] Ibíd.
[282] Ibíd.
[283] Ibíd.
[284] Ibíd.

permissiveness limit established in Resolution 627 of 2006[285], for Sector D, reporting sound levels greater than 45 dB (A).

- The monitoring point R4 presented the lowest levels of environmental noise during the daytime, during the working and non-working days, this is associated with the absence of homes near the monitoring point.

For all the monitoring points, natural sounds generated mainly by birds and insects were perceived.

- Prediction modeling of sound pressure levels during the operation of the viaduct

In order to evaluate the emission of noise in the environment generated by the operation of the viaduct for the transit of vehicles that carry the export and import type cargo unloaded in the Onshore Terminal and Water Terminal of Puerto Bahía Colombia de Urabá SA towards the courtyards and vice versa, a modeling of this scenario was performed to identify the levels of sound pressure contribution (weighted decibels A (dB (A)), which was presented and approved in the ordinary course of the activity licensed for construction of a viaduct as connection between the dock and the port terminal through the file ANLA 2015008528-1-000 of February 20, 2015.

To estimate the aforementioned noise emission, we used the CoRTN model that was developed by Delany et al. 1976[286], from the Department of the Environment of the United Kingdom. In this model the hourly value is considered, it has corrections for the average speed, the percentage of heavy vehicles, the slope and characteristics of the surface of the road

- **Considerations for the model**

Type of Vehicles

Kalmar TR626i / TR632i vehicles, high strength terminal equipment, will be used, they have a capacity of up to 50 tons lifting capacity and 320 tons VCG, see Figure No. 5.264. This makes it ideal for heavy industry, heavy RoRo and trailer trains (see Annex 5.1.4 Air and noise quality).

[285] Ibíd.
[286] DELANY, M.E., HARLAND, D.G., HOOD, R.A. and SCHOLES, W.E. 'The prediction of noise levels L10 due to road traffic', Journal of Sound and Vibration, vol. 48 no. 3. 1976. 305-325 p.

They feature a Volvo D13 engine, which exceeds current emissions requirements and reduces NOx emissions to almost zero.

Figure No. 5.244 Kalmar equipment TR626i / TR632i Transport vehicle that will transit the viaduct.
Source: AG Consultores Ambientales S.A.S., 2015

The Kalmar TR626i / TR632i features a durable, stable and powerful lift platform with active tilt, which allows +/- 10 ° of tilt side of the fifth wheel.

This allows the trailer or gooseneck to follow the terrain without torsional forces in the chassis, ensuring better balanced traction between all the wheels. The driver can balance a trailer with unbalanced load or load that has been moved during transport. The driver easily controls the tilt from the cab. To lower the trailer / lift boom to a pre-set height, the driver just has to touch the joystick.

The complete driving line, including the engine, axle and gearbox, are built for maximum power and efficiency.

The Volvo D13 engine complies with current emission regulations (Stage IIIB / Tier 4i) to reduce the effects on the environment of exhaust emissions from diesel engines. The TR626i / TR632i also injects AdBlue, a benign chemical reagent, into

the exhaust gas to flow and converts nitrogen oxides (NOx) into nitrogen and oxygen.

The selective catalytic reduction (SCR) system combines power increase with fewer emissions. The cooling demands for SCR motors remain the same or even lower than before. In addition, the output power is maximized. This translates into a reduction in costs and simplified installations.

Figure No. 5.245 Kalmar Equipment TR626i / TR632i Transport vehicle that will transit the viaduct.
Source: AG Consultores Ambientales S.A.S., 2015

Volvo D13 engine

Kalmar equipment comes equipped with a Volvo D13 engine, which is certified with GEI 2014 (Greenhouse Gases), the lowest D13 fuel consumption, which saves up to 3% in fuel costs.

The Volvo D13 is a very light and powerful fuel-efficient engine, designed to meet current and future EPA regulations, while improving reliability and reducing operating costs.

The D13 engines are fully compatible with the EPA requirements. All regulated pollutants have been reduced by 99% from untreated levels. Volvo meets these demands with reliability and exceptional economy, in part because it uses selective catalytic reduction for maximum efficiency.

The SCR adopts a passive regeneration concept that uses NOx, instead of diesel fuel to regenerate the soot, which further reduces the cost of operation.

Permissible limits

In accordance with the baseline of the Environmental Impact Study conducted in 2009[287], the permissible use in the area of interest of the project corresponds to Sector C- Restricted Intermediate Noise, Subsector "Zones with industrial permitted uses, such as industries in general, port areas, industrial parks, free zones".

Resolution 0627 of 2006[288] of the Ministry of Environment, Housing and Territorial Development, now the Ministry of Environment and Sustainable Development, established in Chapter II, Art. 9, the Maximum Permissible Standards of Noise Emission Levels expressed in weighted decibels A (dB (A)). For the study area, according to its correspondence sector, we have the values shown in Table No. 5.112.

Table No. 5.97 Maximum permissible standard of noise emission levels expressed in decibels dB (A

SECTOR	SUBSECTOR	Maximum permissible noise emission standards in dB (A)	
		Day	Day
Sector C. Restricted Intermediate Noise	Areas with industrial permitted uses, such as industries in general, port areas, industrial parks, free zones.	75	75

Source: Resolution 627 (April 07, 2006)[289].

[287] PUERTO BAHÍA COLOMBIA DE URABA S.A. and ARAÚJO IBARRA & ASOCIADOS S.A, 2010. Op Cit
[288] COLOMBIA. MINISTERIO DE AMBIENTE, VIVIENDA Y DESARROLLO SOSTENIBLE. Resolution 627 (April, 07, 2006). Op Cit.

[289] Ibíd.

Noise levels in the Study area

On November 30, 2009, Air Clean System S.A. (ACS) conducted an environmental noise monitoring in daytime and night shift at the project's site (see Table No. 5,113).

Table No. 5.98 Equivalent average levels of environmental noise

Point	Equivalent average level (dB(A))	
	Diurnal	Nocturnal
1	54,5	47,3
2	47,6	53,7
3	52,6	49,8

Source: Air Clean System S.A, 2009

In the surrounding areas where the viaduct is located there are no houses, nor populations that receive the noise that will be generated by vehicular traffic.

The viaduct will be built on a low, flooded area, covered with tall grasses, so there are no sources of noise. The noise found in the area corresponds to the noise generated by the wind, the flow of the river León and natural areas.

- **Modeling results**

As a result of the execution of the calculation of the noise mission of vehicular traffic, using the CoRTN calculation algorithm, a prediction of the noise values emitted by the modeled source is obtained at the distances with which the model was fed.

Table No. 5.114 shows the results obtained through the modeling and its respective comparison with the permissible noise emission limits for the national territory, specifically for sector C Restricted Intermediate Noise, Subsector "Zones with industrial permitted uses, such as industries in general, port areas, industrial parks, free zones".

Table No. 5.99 Modeling results of expected noise levels at different distances of Operation of the Viaduct of Puerto Bahía Colombia de Urabá, compared with permissible limits

Distance (m)	dB(A)	Noise Emission Limit (day-night) dB (A)	COMPLIANCE Res 627/2006- 75 dB(A)
0	65,9	75	COMPLIES
10	64,2	75	COMPLIES
20	62,6	75	COMPLIES
50	58,7	75	COMPLIES
100	55,1	75	COMPLIES
200	51,4	75	COMPLIES

Distance (m)	dB(A)	Noise Emission Limit (day-night) dB (A)	COMPLIANCE Res 627/2006- 75 dB(A)
500	46,5	75	COMPLIES
1000	42,7	75	COMPLIES
1500	40,5	75	COMPLIES
2000	38,9	75	COMPLIES
2500	37,7	75	COMPLIES
3000	36,7	75	COMPLIES

Source: AG Consultores Ambientales S.A.S., 2015

The results show that the modeled source has a sound pressure emission level of 65.9 dB (A), during the operational phase. In the same way that this value is attenuated with distance and that the values obtained are complying with the levels established in Colombian regulations.

To graph the results of the CoRTN model, the ArcGIS 10.1 tool was used. Geographic Information Systems use several methods to model the behavior of variables that change with distance.

One of the most useful aspects has been the study of the spatial variability of noise and the prediction of values at points not sampled through the use of interpolations, functionality is widely used in conjunction with sampling methodologies.

In particular, the interpolation with geostatistical analysis is based on the theory of regionalized variables and their dependence and autocorrelation, under a spatial variability framework [290].

The sound pressure levels were plotted using the Kriging interpolation in ArcGis, obtaining the graphs shown in the annexed files by means of isophones (see Figure No. 5.266 and Figure No. 5.267).

[290] TRANGMAR, B.B., POST, R.S. & UEHARA, G. *Application of geostatistics to spatial studies of soil properties.* On: Advances in Agronomy. 1985. 38:45-94.

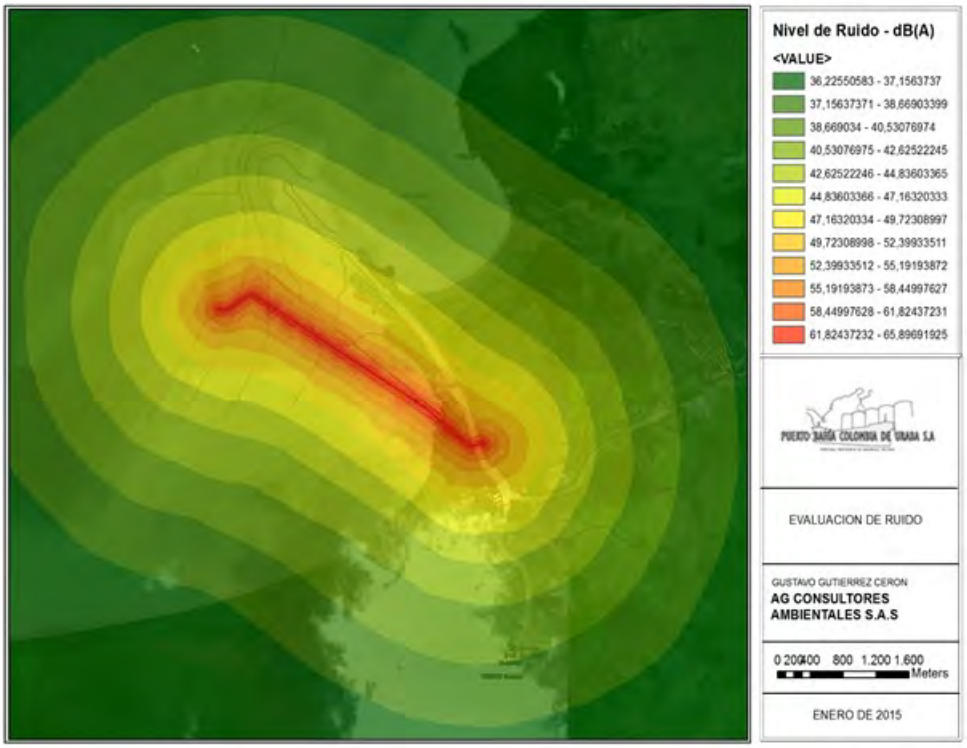


Figure No. 5.246 Sound pressure levels, estimated for vehicular traffic of the viaduct of the Puerto Bahía Colombia de Urabá Project.
Source: AG Consultores Ambientales S.A.S., 2015

Figure No. 5.266------Noise Level dB(A)-----Noise evaluation---January 2015

The value obtained in the emission source, that is, in the viaduct (65.9 dB (A)), is attenuated with distance uniformly, so that in the nearest town, which is Nueva Colonia, we obtain a level of 36.7 dB (A).

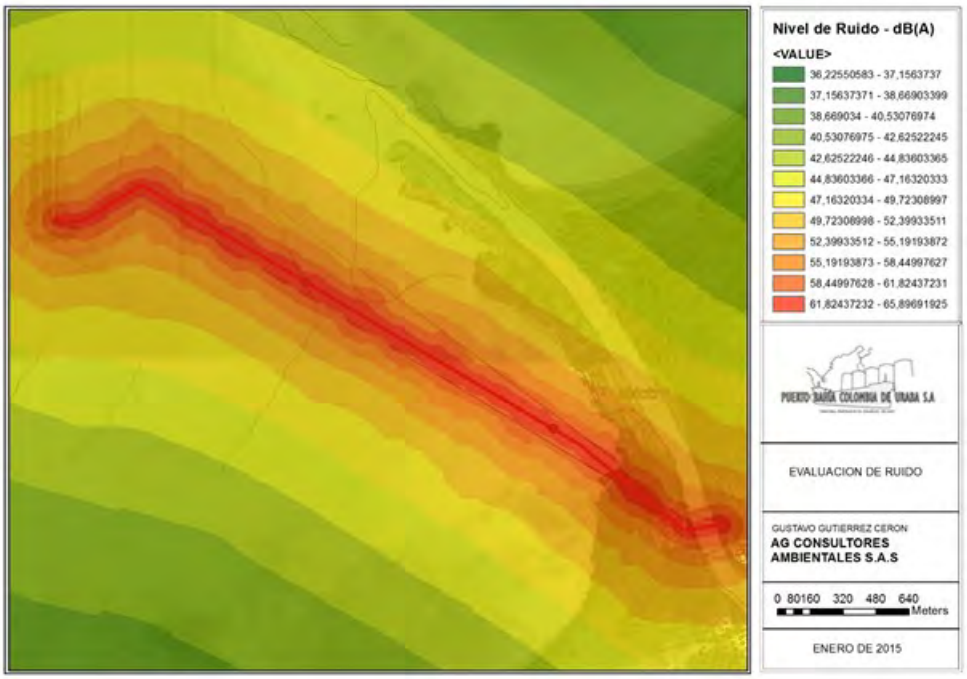


Figure No. 5.247 Sound pressure levels detail, estimated for vehicular traffic by the Viaduct of the Puerto Bahía Colombia de Urabá project.
Source: AG Consultores Ambientales S.A.S., 2015

No live barriers or reflective facades were considered for the modeling, due to the location of the project in an isolated area and where the nearest population is located a couple of kilometers away. For this reason, the result yields a series of isophones parallel to the source of emission (viaduct traffic). The noise values (dB (A)) of each isophones are the values given by the CoRTN.

- **Conclusions**

In the prediction of the acoustic impacts for vehicular traffic in the viaduct of the Puerto Bahía Colombia project in Urabá, the expected emission for a vehicular flow of 50 vehicles / hour is of 65.9 dB (A) at the edge of the viaduct, sound that fades with distance.

The flooded area of wooded pastures, high secondary vegetation and dense high mangrove through which the viaduct route passes would be affected by the acoustic emission in a strip parallel to the road, 200 m wide on the sides of the road, to

estimated values between 65.9 dB (A) on the viaduct edge, up to 51.4 dB (A) at 200 m distance.

There are no populated areas in the area that receive sound pressure levels. The sector of Nueva Colonia, located about 3 km away, is estimated to contribute by vehicular traffic with a residual sound pressure level of 36.7 dB (A).

The noise emission levels estimated in the study, are below the permissible limits established in Resolution 627 of 2006[291] of the MADVD today MADS, both for the day and night shift, which is stipulated in 75 dB (A), for Sector C- Restricted Intermediate Noise, Subsector "Areas with industrial permitted uses, such as industries in general, port areas, industrial parks, free zones". This is because the maximum value obtained in the modeling is 65.9 dB (A) at the point of emission.

For the sector of Nueva Colonia, which is the nearest town, a contribution of less than 40 dB (A) is estimated, which is below the permissible noise emission limits for residential areas established in the regulations of 65 dB (A) in the day and 50 dB (A) at night.

- Model of prediction of sound pressure levels

The purpose of the modeling is to predict the acoustic impact of the operation activities of vehicular sections between the district of Nueva Colonia and the Puerto Bahía Colombia De Urabá Port Terminal project; from the traffic study carried out for the same, by means of the acoustic prediction software CadnaA V4.5; under the French Standard "NMPB Routes 96" and taking into account two (2) individual scenarios.

- **Modeling scenarios**

Scenario I

Operation of existing roads, "Nueva Colonia - Puerto Bahía Colombia De Urabá Estate". This scenario has a section that comes from the north-western part of the urban area of Nueva Colombia, bordering the district, and reaching the site where the Puerto Bahía Colombia De Urabá project will be located. This road presents several bifurcations towards banana plantations and wineries that will generate a

[291] COLOMBIA. MINISTRY OF ENVIRONMENT, HOUSING AND SUSTAINABLE DEVELOPMENT. Resolution 627 (April 07, 2006). Op Cit.

reduction of the vehicular flow as it advances towards the property, however, they will not be considered within the modeling.

Scenario II

Projected roads operation, "Nueva Colonia - Puerto Bahía Colombia De Urabá". This road has a slightly different route to the existing road (scenario I), but in the same direction to the Puerto Antioquia project site. See Figure No. 5.268.

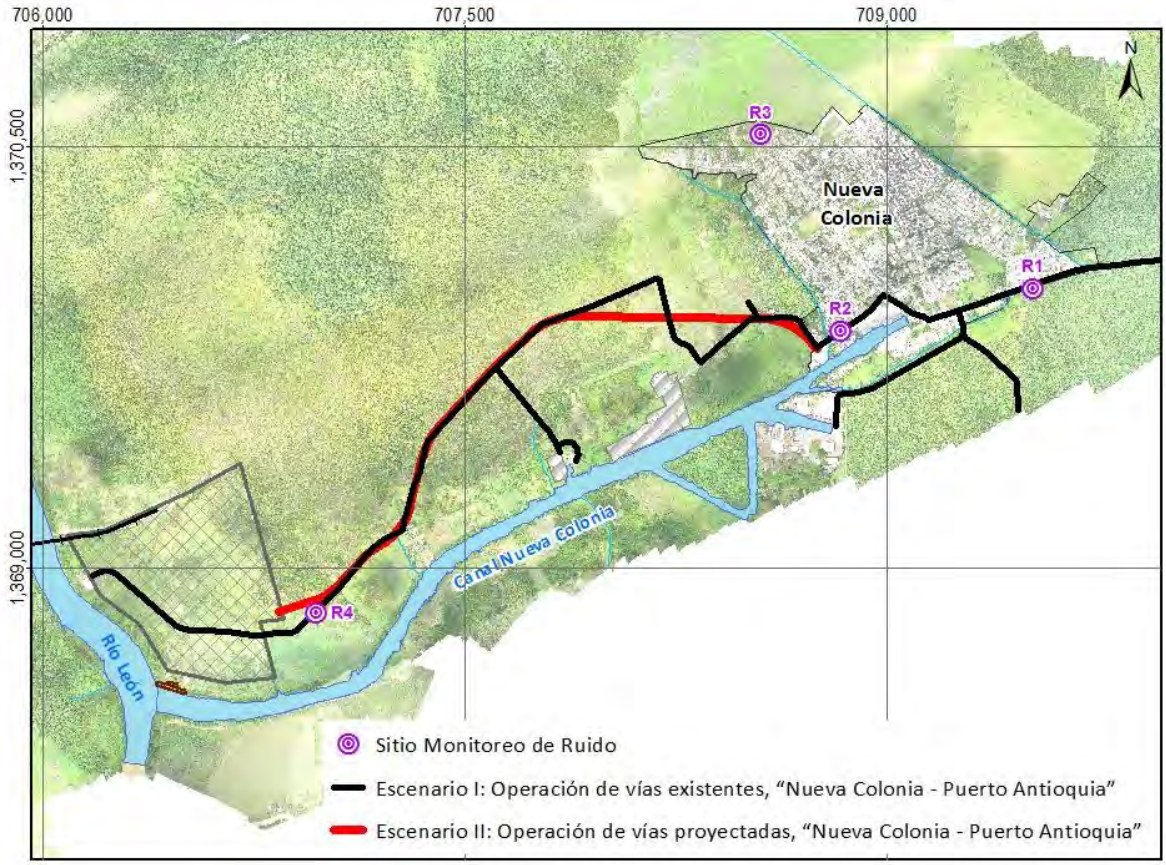


Figure No. 5.248 Location of scenarios to be modeled
Source: SGS COLOMBIA S.A, 2015

- **Identification of sound sources**

Scenario I

The vehicle flow of the sections of this scenario was extracted from vehicular traffic from the "Rio Grande - Nueva Colonia" road of the Transit Study [292]. By 2015, there is a total of 1,912 vehicles / day, traveling through the section "Rio Grande-Nueva Colonia", of which 268 are light vehicles and 1644 correspond to heavy vehicles (buses and trucks); this is equivalent to 86% of heavy vehicles and 14% of light vehicles.

Table No. 5.100 Vehicle capacity between Río Grande - Nueva Colonia

TRAMO RIO GRANDE - NUEVA COLONIA												
AÑO	LIVIANOS		BUSES		CAMIONES							
	TASA	V24H	TASA	V24H	TASA	V24H C2P	V24H C2G	V24H C3	V24H C5	V24H >C5	TOTAL CAMIONES	TOTAL TPDS
2014		259		609		289	73	3	8	604	977	1845
2015	3,37%	268	4,77%	638	3,10%	298	75	3	8	622	1006	1912
2016	3,26%	277	4,66%	668	2,91%	307	77	3	8	640	1035	1980
2017	3,15%	286	4,45%	698	2,92%	316	79	3	8	659	1065	2049
2018	3,02%	295	4,17%	727	2,84%	325	81	3	8	678	1095	2117
2019	2,97%	304	4,09%	757	2,76%	380	254	250	319	1805	3008	4069
2020	2,88%	313	3,93%	787	2,69%	390	261	258	331	1868	3107	4207
2021	2,80%	322	3,70%	816	2,53%	400	268	265	340	1918	3192	4330
2022	2,72%	331	3,65%	846	2,55%	411	276	273	350	1970	3280	4457
2023	2,65%	340	3,52%	876	2,49%	421	284	281	359	2024	3369	4585
2024	2,58%	349	3,32%	905	2,43%	432	291	290	369	2078	3460	4714
2025	2,52%	358	3,29%	935	2,37%	443	299	298	379	2133	3552	4845
2026	2,43%	367	3,18%	965	2,32%	453	307	307	390	2190	3647	4979
2027	2,40%	376	3,02%	994	2,19%	464	316	316	401	2246	3742	5112
2028	2,34%	385	2,99%	1024	2,21%	475	324	326	412	2305	3841	5250
2029	2,29%	394	2,91%	1054	2,17%	485	333	335	424	2364	3941	5389
2030	2,24%	403	2,76%	1083	2,12%	496	342	345	435	2425	4044	5530
2031	2,19%	412	2,75%	1113	2,08%	507	351	355	448	2490	4151	5676
2032	2,14%	421	2,68%	1143	1,97%	518	360	366	461	2555	4260	5824
2033	2,07%	430	2,55%	1172	1,99%	529	370	377	475	2622	4373	5975
2034	2,05%	439	2,54%	1202	1,96%	540	379	388	489	2691	4488	6129
2035	2,01%	448	2,42%	1231	1,92%	551	389	400	503	2761	4605	6284
2036	1,97%	457	2,42%	1261	1,88%	562	400	412	518	2833	4725	6443
2037	1,94%	466	2,36%	1291	1,79%	574	410	424	534	2906	4847	6604
2038	1,90%	475	2,26%	1320	1,81%	585	421	436	549	2981	4973	6768
2039	1,86%	484	2,26%	1350	1,78%	596	432	449	566	3058	5101	6935
2040	1,81%	493	2,21%	1380	1,75%	608	443	463	582	3136	5233	7106

Source: Transit Study, 2015[293]

Table No. 5.115

YEAR-------LIGHT-------BUSES-------TRUCKS

292 PIO SAS y GRUPO VIAL. Basic and detailed engineering, procurement and supply of materials, construction, assembly and commissioning of the works required for phase 1 of the Puerto Antioquia Port Terminal located at the mouth of the León River, in the Gulf of Urabá - Transit Study, Department of Antioquia. Cali, 2015. 203 p.

293 Ibíd

RATE----V24H

In this scenario, 100% of all vehicles arriving from Rio Grande are taken as a whole, of which 30% will take the road that goes to the south-west of the urban area and 30% to the south-east. The remaining 40% will continue westwards from the urban area of Nueva Colonia and approximately 1.5 km westwards a new division will be presented in the section, of which 30% of the vehicle flow will go south and finally only 10% will continue to the area of the project site as shown in Figure No. 5.269

It should be noted that only the routes that go directly from Nueva Colonia to the property were considered in the calculation of the modeling (highlighted in blue, Figure No. 5.269).

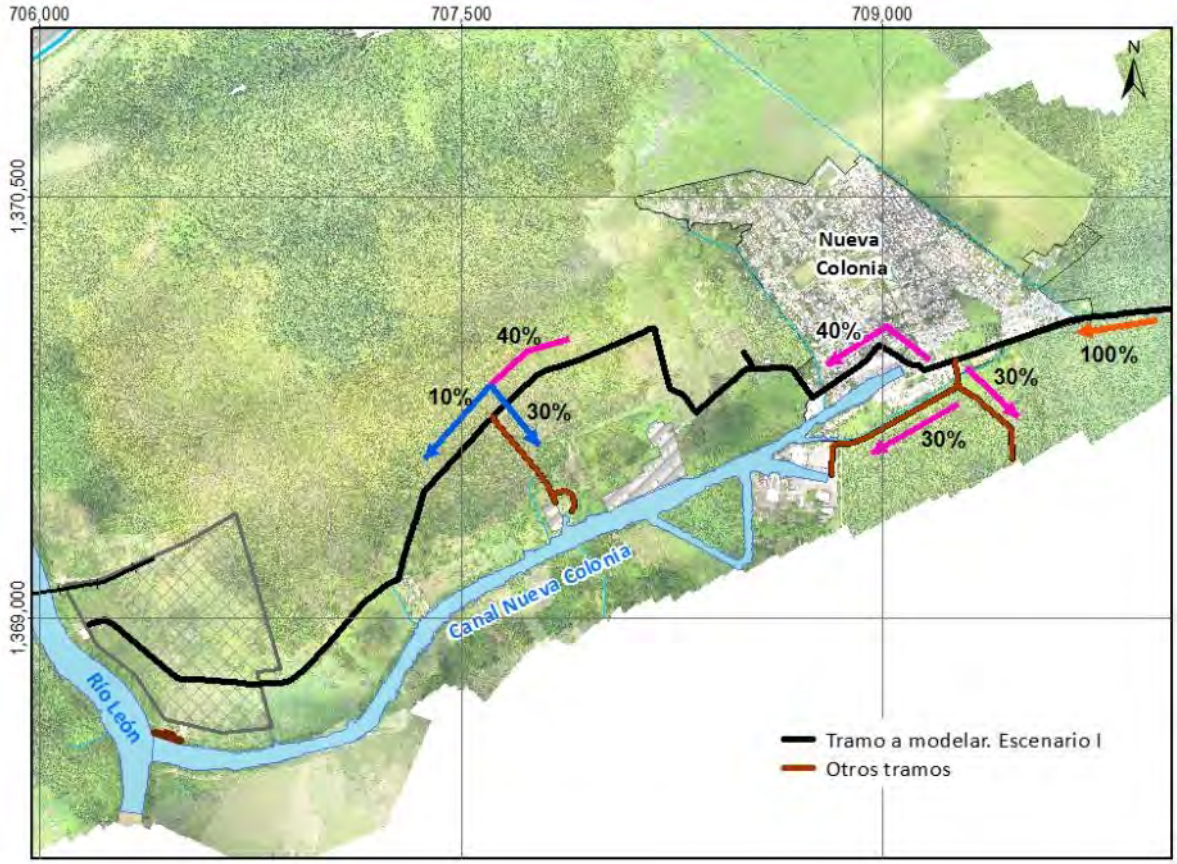


Figure No. 5.249 Vehicular bifurcation on scenario I
Source: SGS COLOMBIA S.A, 2015

Scenario II

For this scenario, the projected road that will connect the project of Puerto Bahía Colombia De Urabá with the municipality of Nueva Colonia, which has a length of 2.46 km, will be modeled.

In order to simulate an acoustic environment that can be considered as a critical scenario, and that can be verified in the medium term through noise measurements, the traffic information corresponding to the year 2025 is chosen, because the project will be fully operational for that year and will have a considerably high traffic flow.

In 2025, according to the traffic study, the projected section has a traffic flow of 10,933 vehicles / day, which will travel from Nueva Colonia to Puerto Bahía Colombia de Urabá, 4,365 will be light vehicles and 6,568 will correspond to heavy vehicles (buses and trucks); this is equivalent to 60% of heavy vehicles and 40% of light vehicles, see Table No. 5.116.

By 2025, the section projected according to the traffic study[294] will present a traffic flow of 10,933 vehicles / day, which will travel from Nueva Colonia to Puerto Bahía Colombia de Urabá, of which approximately 60% correspond to heavy vehicles (buses and trucks) and the remaining 40% to light vehicles, see table Figure No. 5.269

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Table No. 5.101 Prediction of vehicular flow Nueva Colonia - Puerto Bahía Colombia De Urabá

TRAMO NUEVA COLONIA - PUERTO ANTIOQUIA									
AÑO	LIVIANOS	BUSES	CAMIONES						
	V24H	V24H	V24H C2P	V24H C2G	V24H C3	V24H C5	V24H >C5	TOTAL CAMIONES	TOTAL TPDS
2014									
2015									
2016									
2017									
2018									
2019	3655	2750	112	420	607	389	1221	2750	9154
2020	3784	2847	116	433	625	404	1270	2847	9477
2021	3894	2929	119	446	644	415	1305	2929	9752
2022	4006	3014	123	459	663	427	1342	3014	10034
2023	4122	3101	126	473	683	439	1380	3101	10325
2024	4242	3191	130	487	704	452	1419	3191	10624
2025	4365	3284	134	502	725	464	1459	3284	10932
2026	4492	3379	138	517	747	478	1500	3379	11250
2027	4622	3477	142	532	769	491	1542	3477	11576
2028	4756	3578	146	548	792	506	1586	3578	11912
2029	4894	3682	151	565	816	520	1631	3682	12258
2030	5037	3789	155	582	840	535	1677	3789	12615
2031	5188	3903	160	599	866	551	1727	3903	12993
2032	5343	4020	165	617	891	568	1779	4020	13383
2033	5504	4140	170	635	918	585	1833	4140	13784
2034	5669	4265	175	654	946	602	1888	4265	14198
2035	5839	4393	180	674	974	620	1944	4393	14624
2036	6014	4524	185	694	1003	639	2002	4524	15063
2037	6194	4660	191	715	1033	658	2063	4660	15515
2038	6380	4800	197	737	1064	678	2124	4800	15980
2039	6572	4944	203	759	1096	698	2188	4944	16459
2040	6769	5092	209	782	1129	719	2254	5092	16953

Source: Transit Study, 2015[295]

❖ Data to be imported for the prediction model

- Wind Rose: The wind rose within CadnaA is set with information on the 2014[296] statistical data, because the direction of the wind tends to change the way in which the sound is propagated by air.

295 Ibíd
296 Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia – IDEAM. Bogotá, 2014.

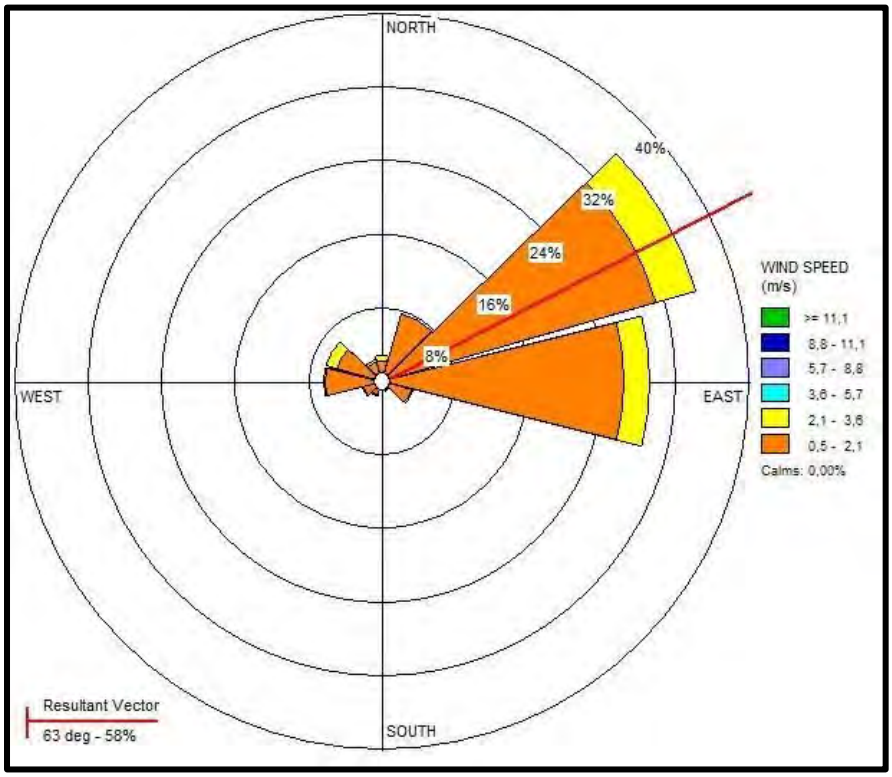


Figure No. 5.250 Wind Rose
Source: SGS COLOMBIA S.A, 2015

- Relative humidity average: 83 %
- Average temperature: 27°C
- Level curves are imported in shape format and are a relevant factor in the modeling because the variation of their levels influences the dispersion and diffraction of sound waves, phenomena that are decisive in the calculation of sound levels.

We proceed to verify the topographic properties of the shapes of the contour lines by modeling in 3D through CadnaA, likewise, the houses surrounding the project area are located and assigned a certain height, in order to simulate the effects of sound shielding that is created because of the facades of the same. Finally, a satellite image of the area is imported as a tool to recognize the surroundings and sensitive areas of the project.

- The information on vehicular traffic capacity and percentage of heavy vehicles of each scenario is entered according to Table No. 5.115 and Table No. 5.116, which are consolidated in Table No. 5.117.

- The four (4) receivers in which environmental noise monitoring was done were created, in order to compare the results in such points.

Table No. 5.102 Classification of sections, scenarios I and II.

Scenario (year)	Description Section	Count (Q)			Heavy vehicles (%)		Maximum speed		PWL Result (Law')		Section length
		Total Veh/day	Vehicle/time				Light	Heavy	Day	Night	
			Day	Night	Day	Night	(km/h)	(km/h)	(dBA)	(dBA)	(m)
I (2015)	New Colonia entrance (100% of traffic)	1912	80.0	80.0	86.0	86.0	100	100	84.3	84.3	499
I (2015)	Section to the West of New Colonia (40% of traffic)	765	32.0	32.0	86.0	86.0	100	100	80.3	80.3	2148
I (2015)	Last section to the project site (10% of traffic)	192	8.0	8.0	86.0	86.0	100	100	74.3	74.3	2011
II (2025)	Nueva Colonia - Puerto Antioquia	10933	455.0	455.0	60.0	60.0	100	100	90.5	90.5	2461

Source: SGS COLOMBIA S.A, 2015

❖ Analysis of results

The results obtained by the CadnaA acoustic prediction model are reflected in noise maps that represent the A-weighted Equivalent Continuous Sound Pressure Level (Leq (A)) within a previously configured grid, with receiver points separated by 10m from each other. These sound pressure levels are represented by colors that divide the same in ranges of 5 and 1 dB (A) depending on the format in which they are exposed.

Scenario I

- Figure No. 5.271 represents the prediction of sound pressure levels dB (A), within the area of interest of the port terminal Puerto Bahía Colombia

De Urabá, for Scenario I, generated by the acoustic prediction software CadnaA, in color format "Raster" and that provides a general idea of the levels generated by the operation activities of the roads.

- Figure No. 5.272 incorporates the prediction of sound pressure levels dB (A), within the area of interest of the port terminal Puerto Bahía Colombia De Urabá, for scenario I, generated by the acoustic prediction software CadnaA, in areas of equal sound level and exposes the areas of direct(Leq> 50 dB) and indirect (Leq> 30 dB) influence of the activities of the operation, identifying homes in the area and other points of interest within the urban area of Nueva Colonia.

- Figure No. 5.273 shows the sound pressure levels expressed in dB (A) within the area of interest of the port terminal project Puerto Bahía Colombia De Urabá, for Scenario I, with a subdivision of degraded colors in the 1dB range. Likewise, it is superimposed with an ortho-photograph of the area in order to have real references of it and the area of influence.

- Figure No. 5.274 and Figure No. 5.275 show the sound pressure levels expressed in dB (A) for the daytime and nighttime hours within the area of interest of the port terminal Puerto Bahía Colombia De Urabá Project, for Scenario I, in lines of equal sound level format or isophones. It is superimposed with an ortho-photograph of the area extracted from Google Earth. See maps MOD_LA_PTO_ANT_29_RuidoE1_D and MOD_LA_PTO_ANT_30_RuidoE1_N.

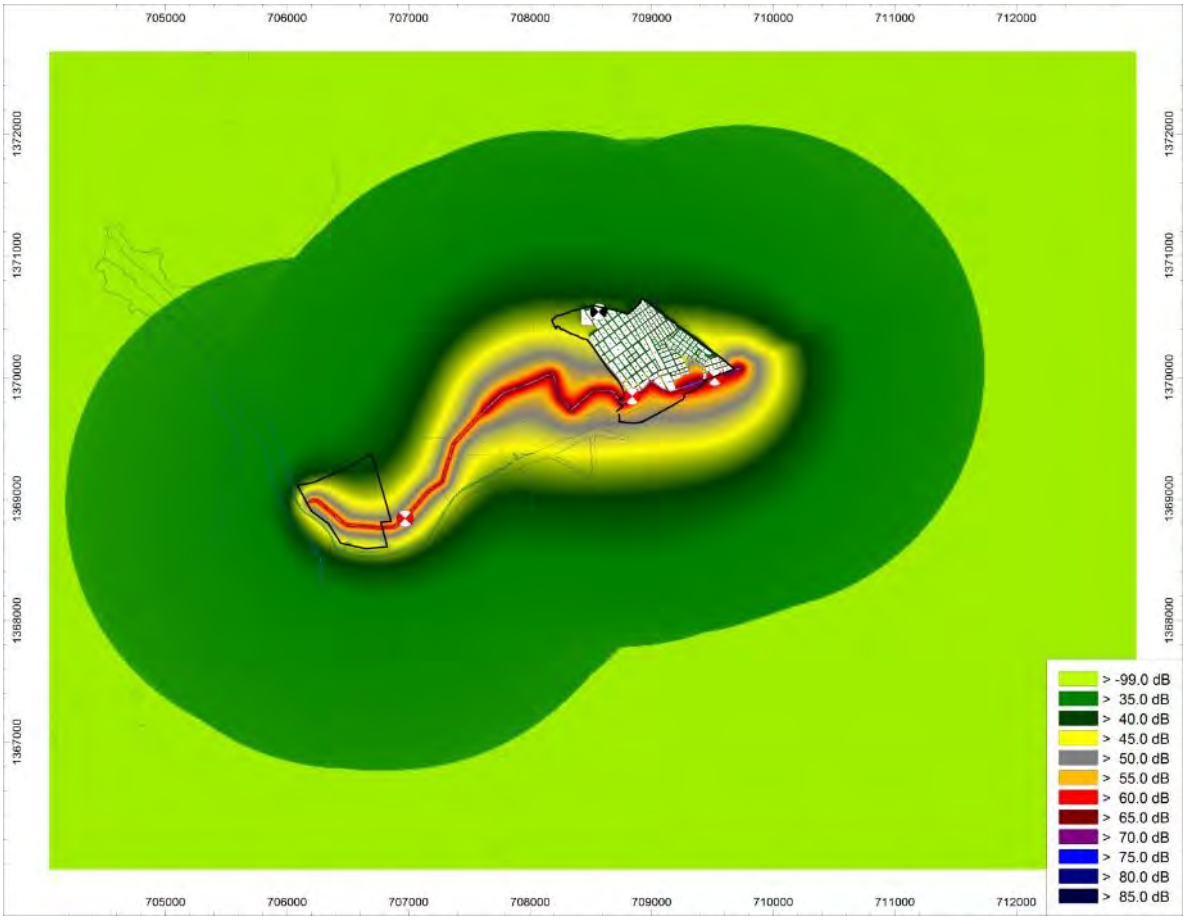


Figure No. 5.251 Noise Map Generated by CadnaA - Raster Format. Scenario I. CadnaA.
Source: SGS COLOMBIA S.A, 2015 with CadnaA Software, 2015

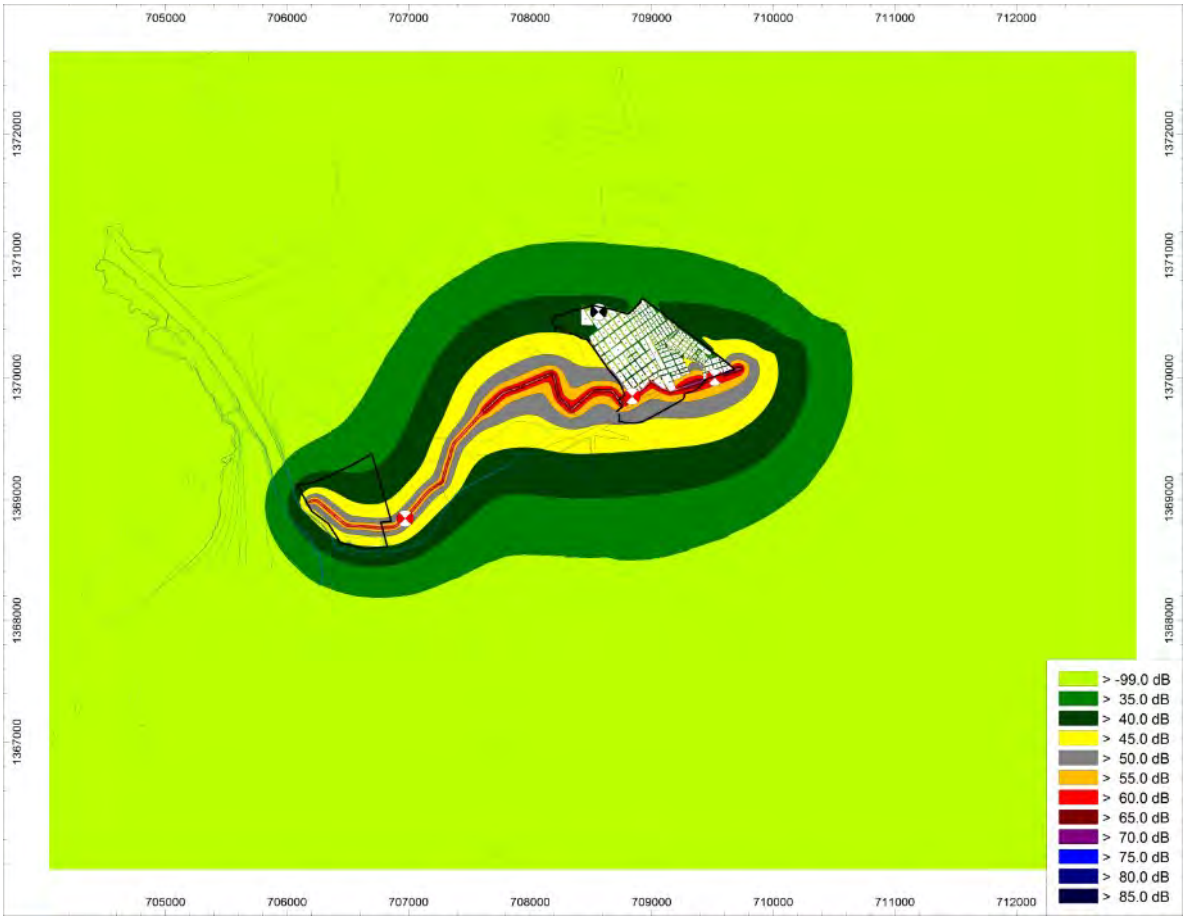


Figure No. 5.252 Noise Map in Noise Areas Generated by CadnaA. Scenario I, CadnaA

Source: SGS COLOMBIA S.A, 2015 with the CadnaA Software, 2015

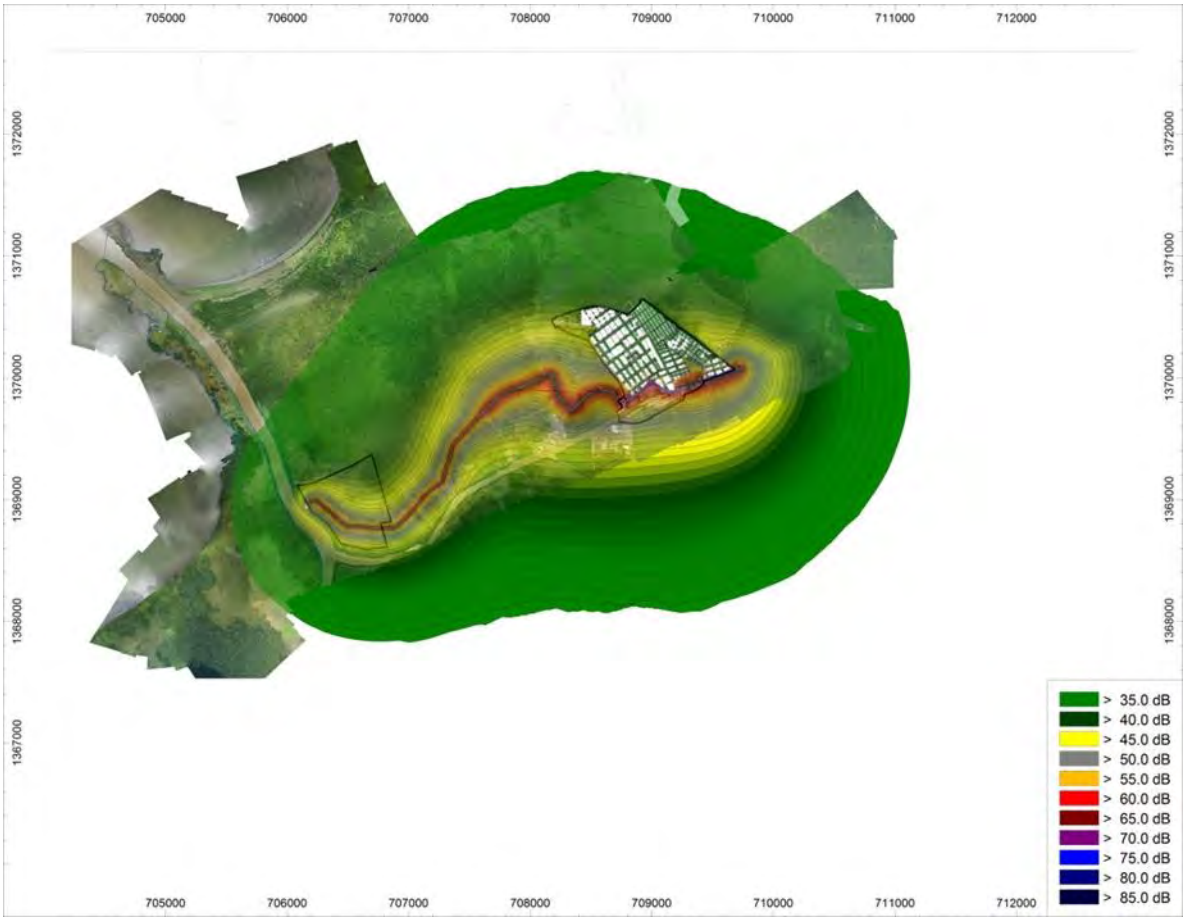
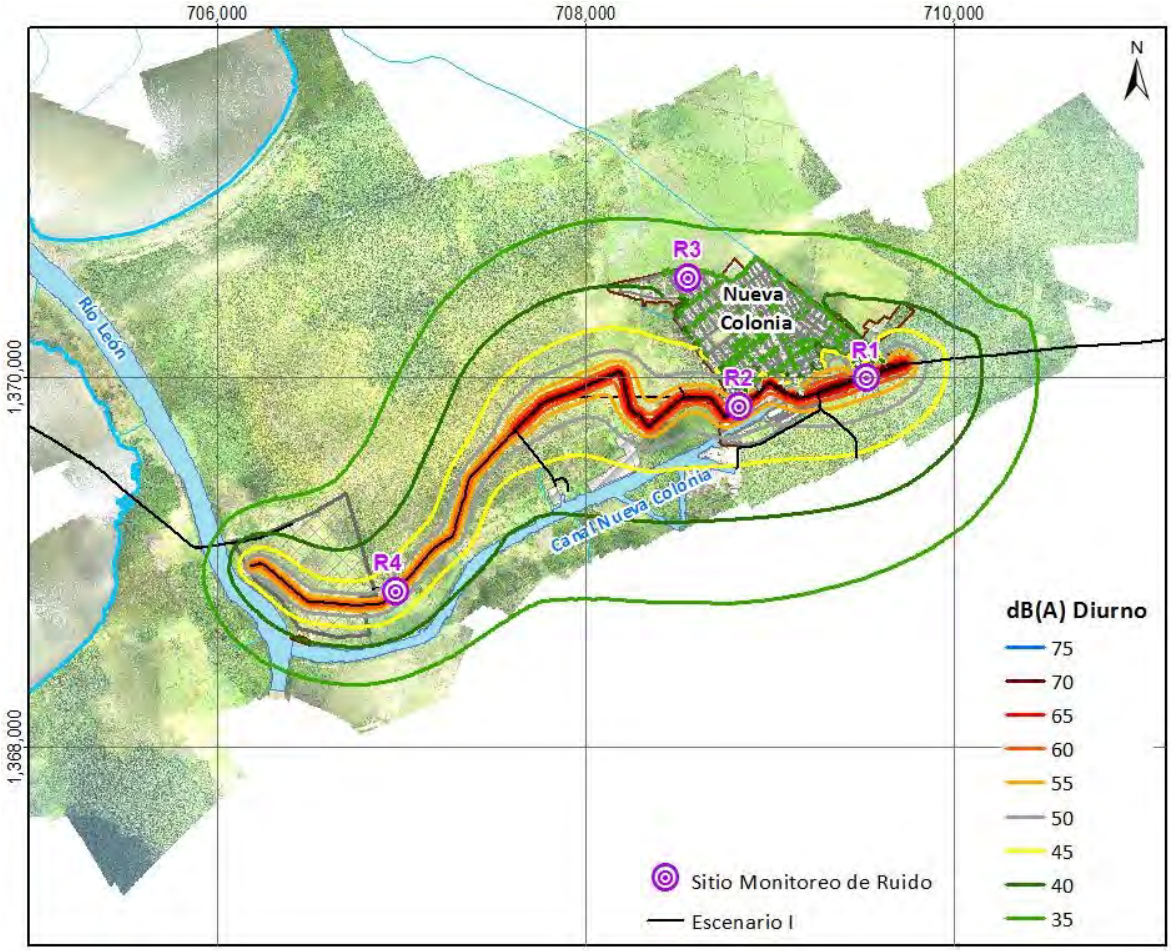


Figure No. 5.253 Noise Map in “Areas of Equal Sound Level Separation: 1 dB" format. Scenario I. CadnaA.
Source: SGS COLOMBIA S.A, 2015 with CadnaA Software, 2015



Noise map in "Equal Sound Level Separation Lines" format. Scenario I. Daytime Schedule. CadnaA.

Source: CadnaA, 2015 modified by Aqua & Terra Consultores Asociados., 2015.

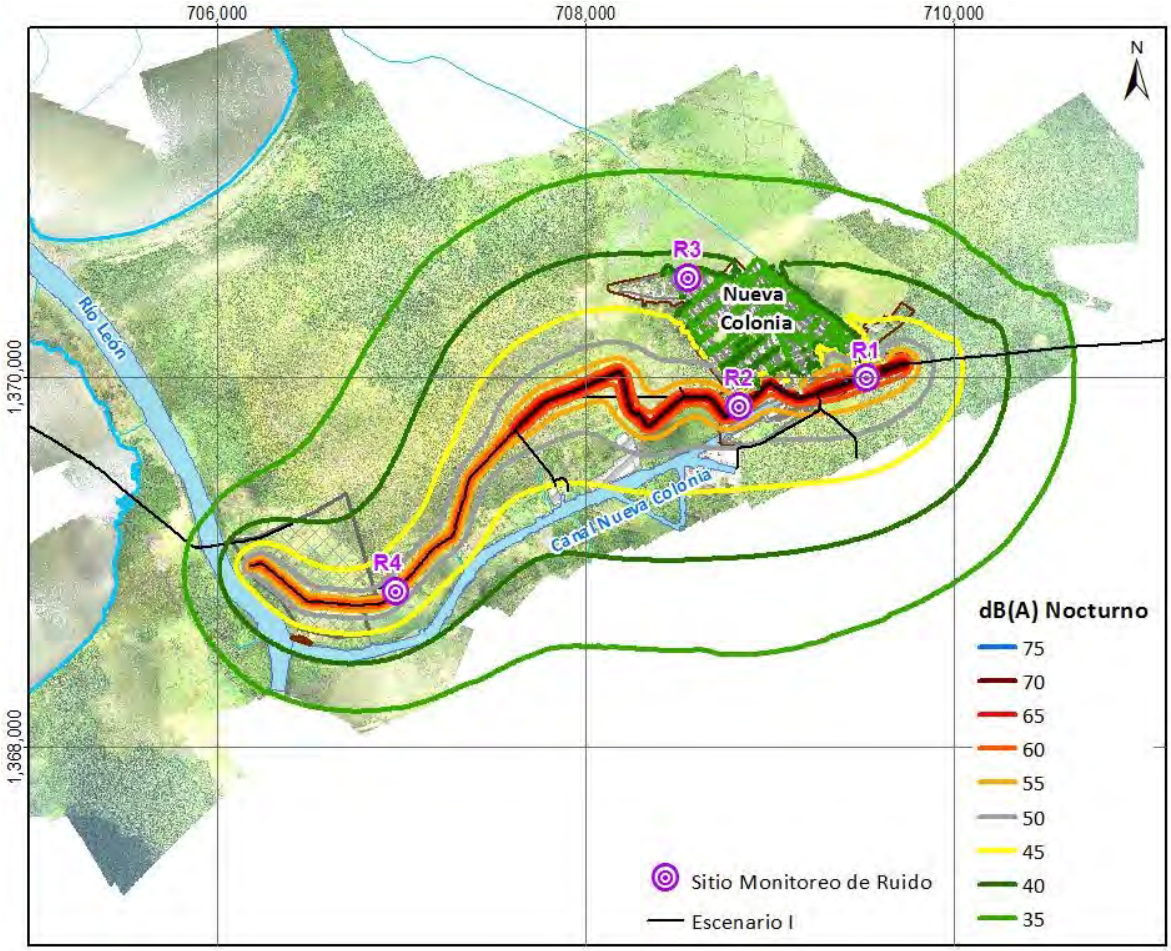


Figure No. 5.254 Noise map in "Equal Sound Level Separation Lines" format. Scenario I. Night Schedule. CadnaA.
Source: CadnaA, 2015 modified by Aqua & Terra Consultores Asociados., 2015.

Scenario II

- Figure No. 5.276 represents the prediction of Sound Pressure Levels dB (A), within the area of interest of the Port Terminal of Puerto Bahía Colombia de Urabá, for Scenario II, generated by the acoustic prediction software CadnaA, in "Raster" color format and that provides a general idea of the levels caused by the Operation activities.

  - Figure No. 5.277 incorporates the prediction of Sound Pressure Levels dB (A), within the area of interest of the Port Terminal of Puerto Bahía

Colombia de Urabá, for Scenario II, generated by the acoustic prediction software CadnaA, in Areas of equal sound Level and exposes the areas of direct (Leq> 50 dB) and indirect (Leq> 30 dB) influence of the activities of the Operation, identifying homes in the area and other points of interest within the urban area of Nueva Colonia.

- Figure No. 5.278 shows the Sound Pressure Levels expressed in dB (A) within the area of interest of the Puerto Bahía Colombia De Urabá Port Terminal project, for Scenario II, with a subdivision of degraded colors in the 1dB range. It also overlaps with an ortho-photography of the area in order to have real references therein and the area of influence.

- Figure No. 5.279 and Figure No. 5.280 show the Sound Pressure Levels expressed in dB (A) during daytime and nighttime hours within the area of interest of the Puerto Bahía Colombia De Urabá Port Terminal project, for Scenario II, in Equal Sound Level Lines or Isophone Lines format. It is superimposed with an ortho-photograph of the area extracted from Google Earth. See maps MOD_LA_PTO_ANT_31_RuidoE2_D and MOD_LA_PTO_ANT_32_RuidoE2_N.

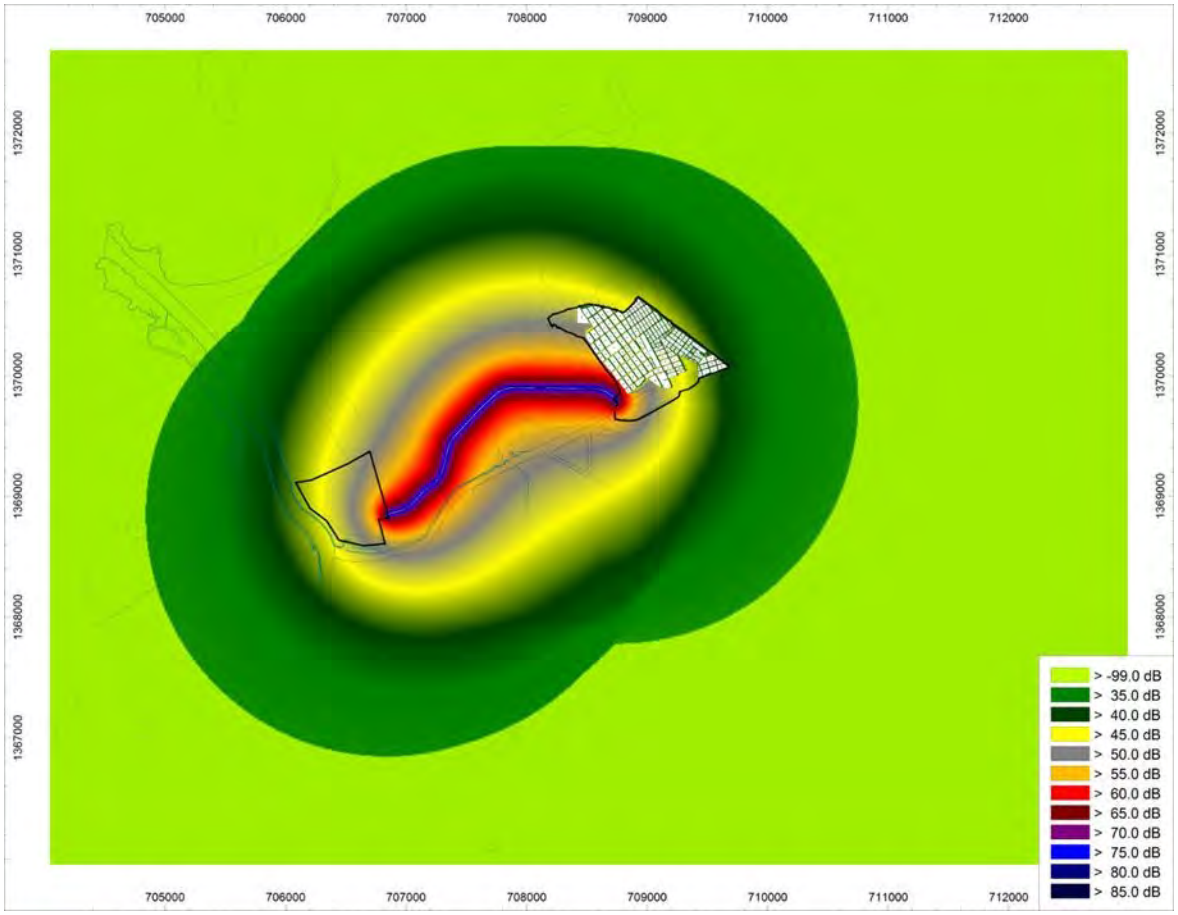


Figure No. 5.255 Noise Map Generated by CadnaA - Raster Format. Scenario II. CadnaA.
Source: SGS COLOMBIA S.A, 2015 with the CadnaA Software, 2015

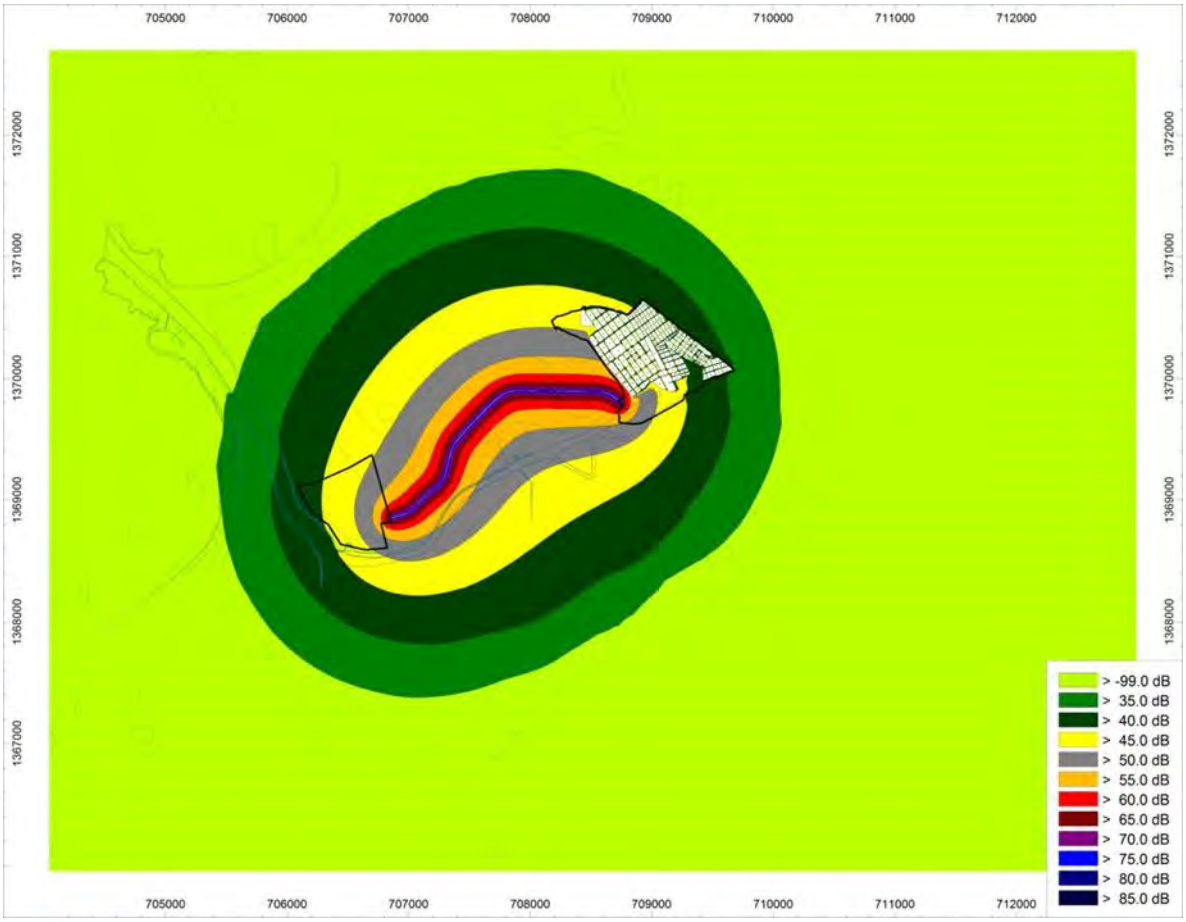


Figure No. 5.256 Figure 2: Noise Map in Noise Areas Generated by CadnaA. Scenario II. CadnaA.

Source: SGS COLOMBIA S.A, 2015 with CadnaA Software, 2015

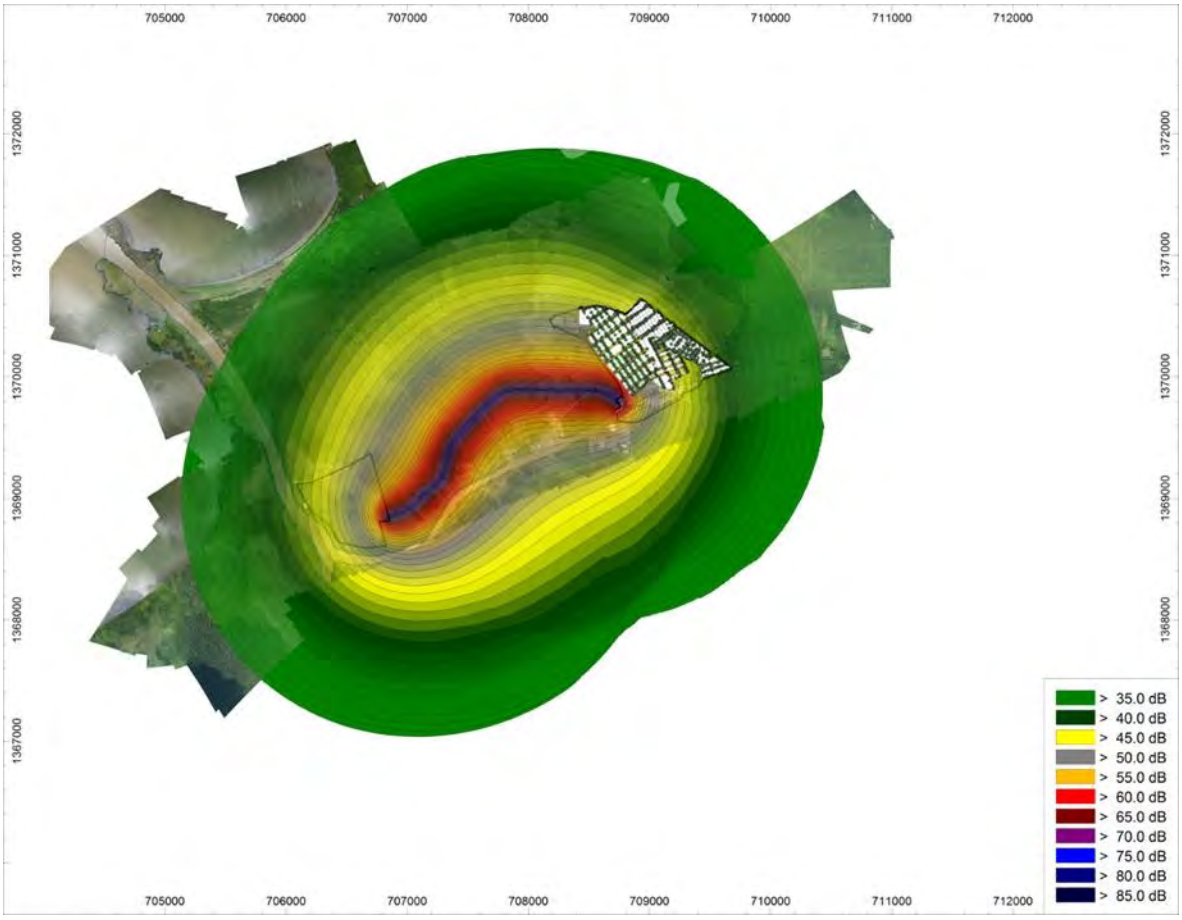


Figure No. 5.257 Map of Noise in "Areas of Equal Sound Level Separation: 1 dB" Format. Scenario

Source: SGS COLOMBIA S.A, 2015 with CadnaA Software, 2015

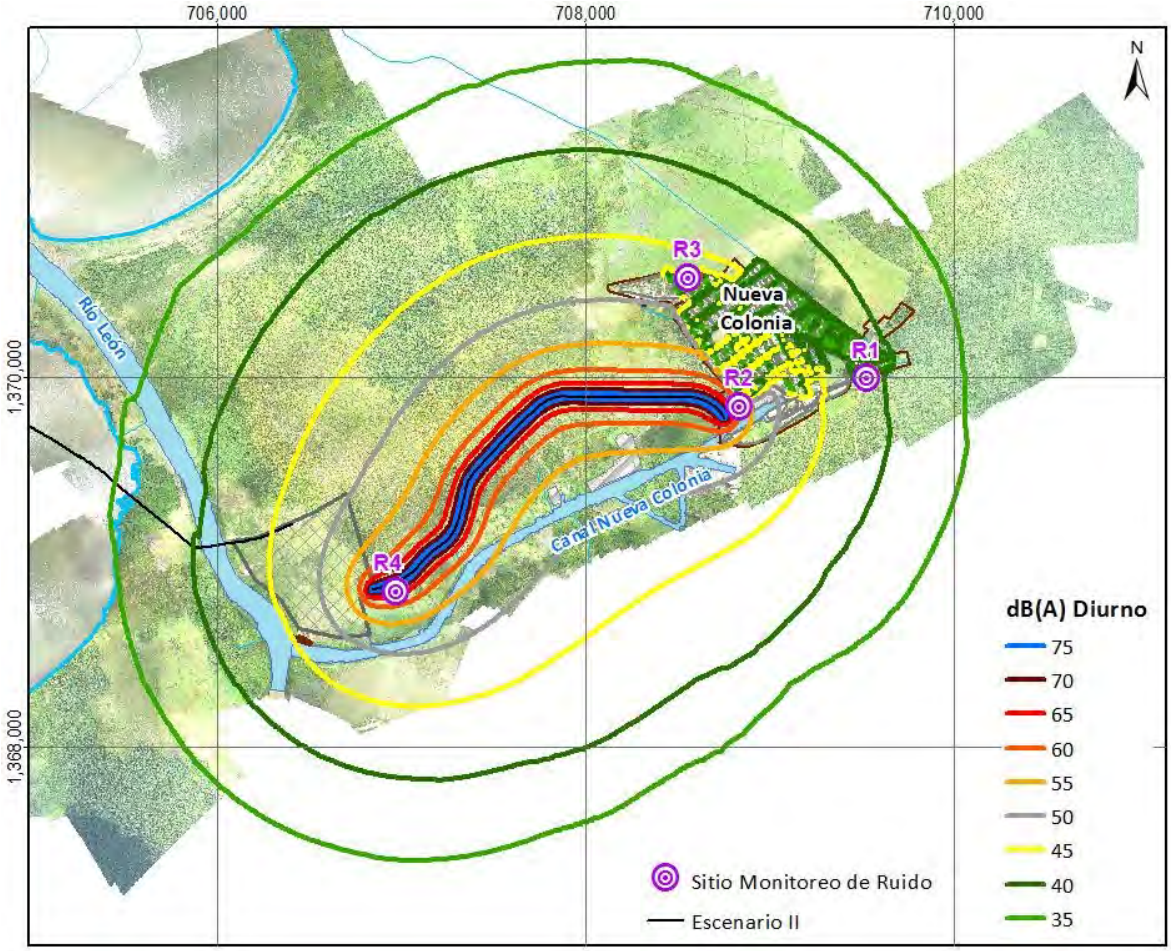


Figure No. 5.258 Noise map in "Equal Sound Level Separation Lines" format. Scenario II. Daytime Schedule CadnaA

Source: CadnaA, 2015 modified by Aqua & Terra Consultores Asociados., 2015.

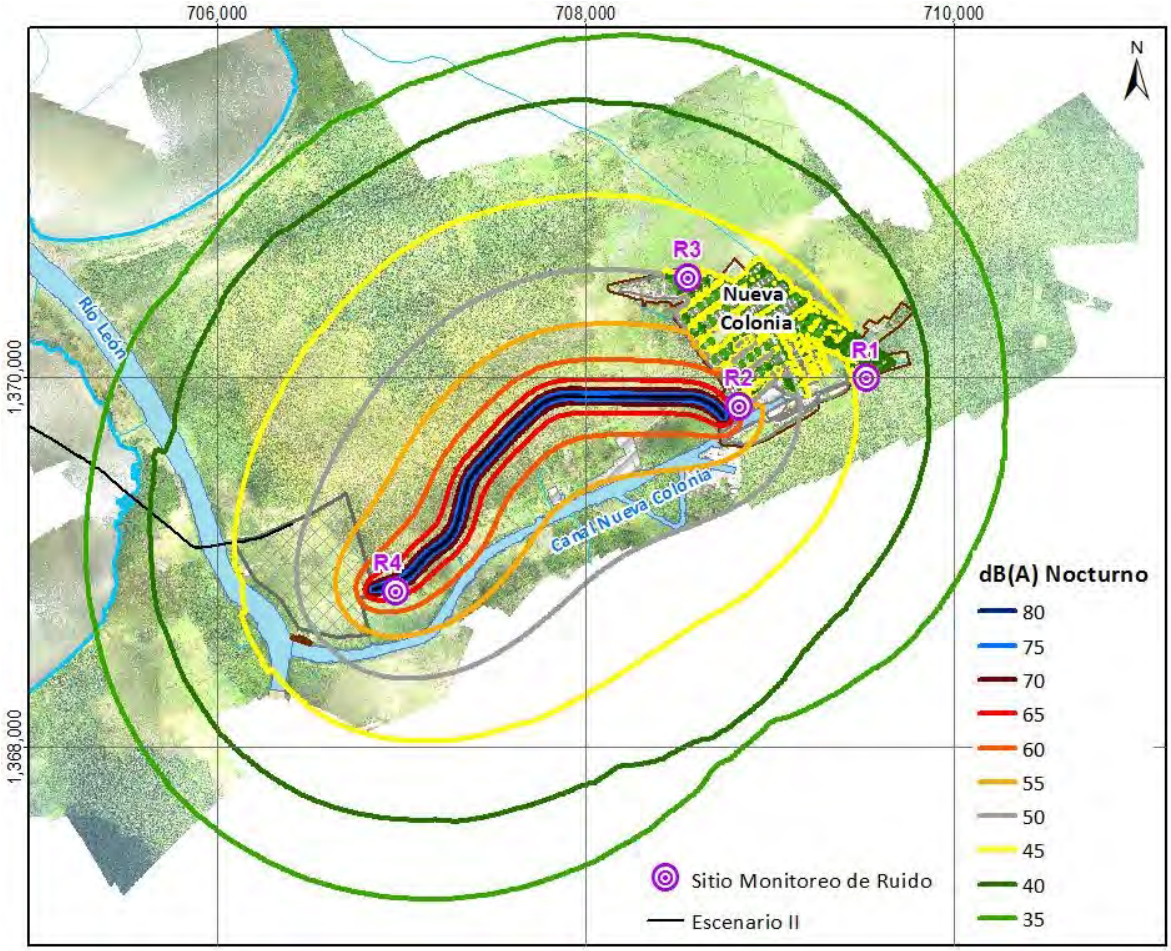


Figure No. 5.259 Noise map in "Equal Sound Level Separation Lines" format. Scenario II. Night Schedule CadnaA

Source: CadnaA, 2015 modified by Aqua & Terra Consultores Asociados., 2015.

❖ Town Centre noise maps Nueva Colonia, scenarios I and II

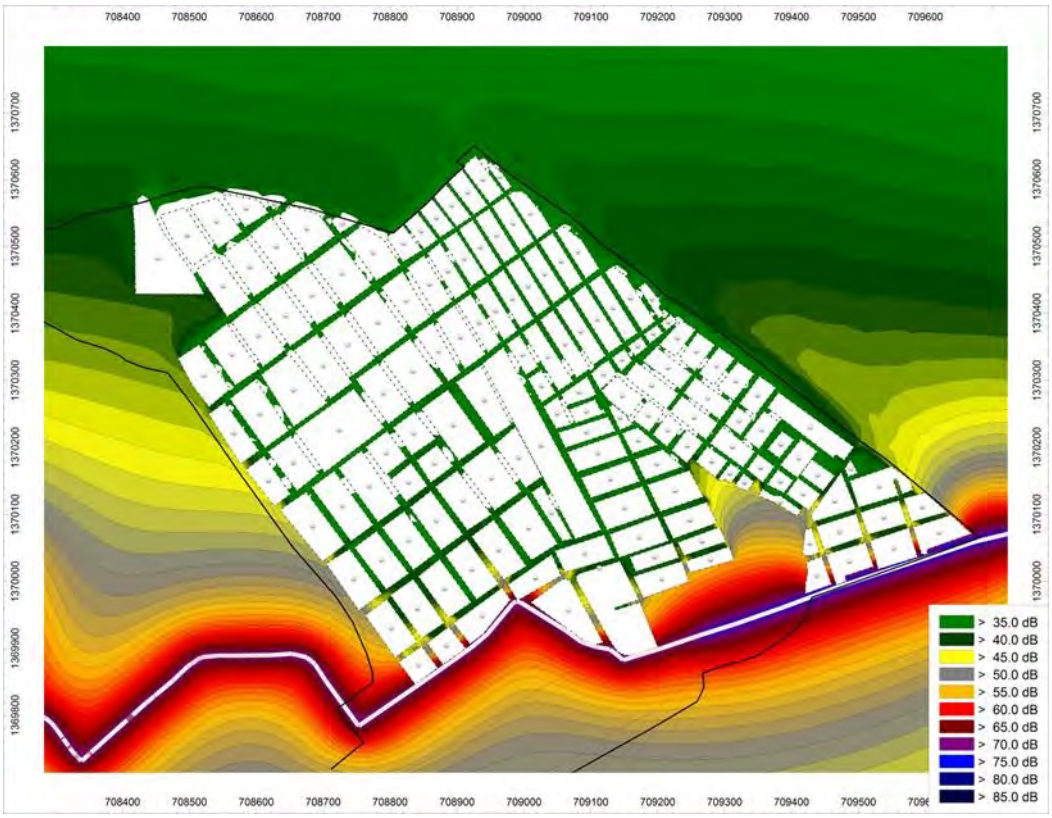


Figure No. 5.260 Noise Map in "Areas of Equal Sound Level Separation: 1 dB" Format. Scenario I - New Colonia Approach. CadnaA.
Source: SGS COLOMBIA S.A, 2015 with CadnaA Software, 2015

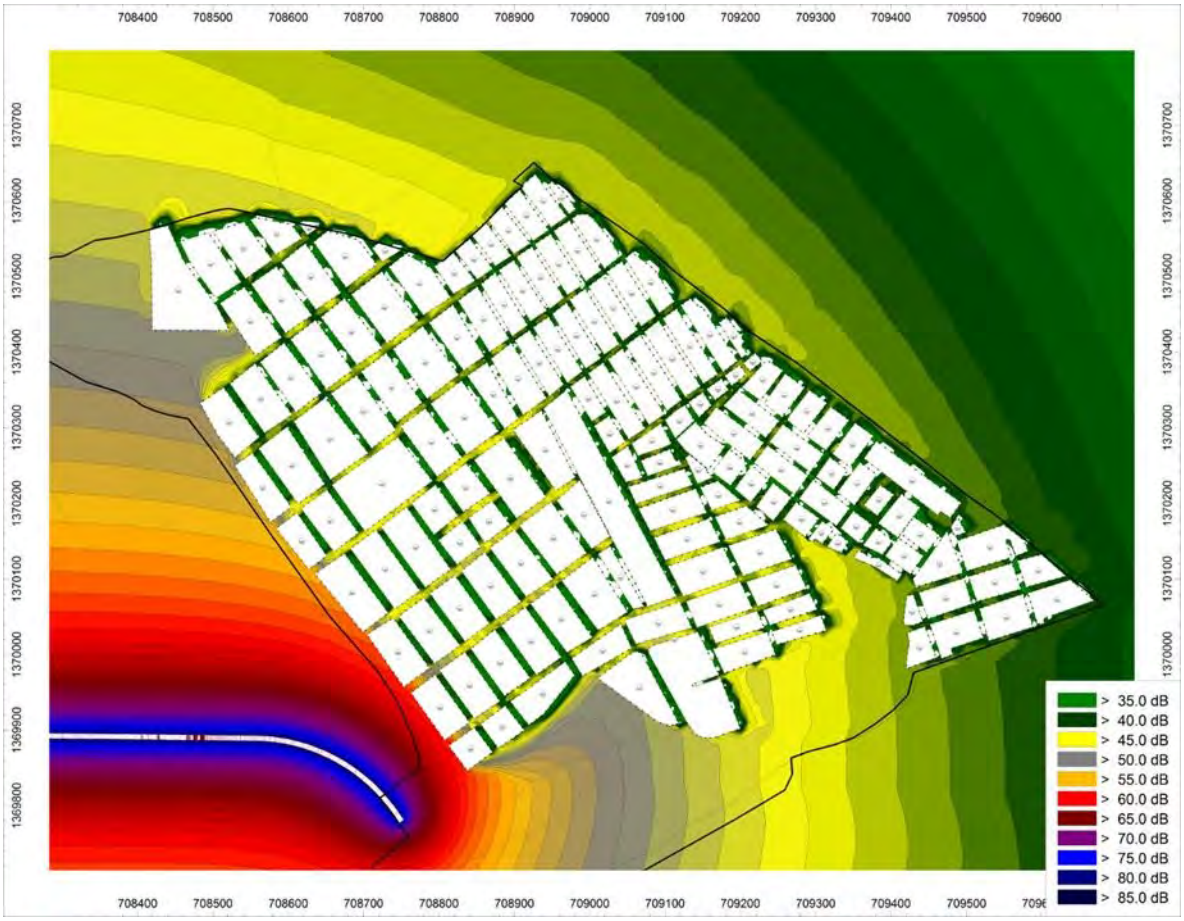


Figure No. 5.261 Noise Map in "Areas of Equal Sound Level Separation: 1 dB" Format. Scenario II - Nueva Colonia Approach.
Source: CadnaA, 2015

- **Comparison of sound pressure levels modeled with maximum levels allowed by current regulations**

Sound pressure levels modeled in populated areas vs. Maximum permissible standards of noise emission levels expressed in dB (A), defined in Resolution 627 of 2006

To make the comparison of sound pressure levels in the cadastral blocks, the maximum allowed value is 70dB (A) in the Day time and 55dB (A) at night time, belonging to the "Sector C. Restricted Intermediate Noise", defined in Article 17 of

Resolution 0627 of 2006 as an inhabited Rural Zone. These reference values are taken following the stipulations in paragraph 2 and 3 of article 9 of this standard, cited below:

2nd paragraph. *Major roads, highways, arterial roads, main roads, in general the roads, are subject to environmental noise measurement, but no noise emission by mobile sources.*

3rd paragraph. *Major roads, highways, arterial roads and main roads, in urban areas or close to towns or human settlements, are not considered as subsectors immersed in other areas or subsectors."*

Moreover, the comparison is made in the four points corresponding to the monitoring of environmental noise within the District's town center in order to compare the calculations of the model with the in-situ measurement, for scenario I, and reference the long-term scenario I. For this comparison, the following values are taken as the maximum value, defined in article 17 of Resolution 0627 of 2006:

- Points 1 and 2: 70dB (A) in the Day time period and 55dB (A) in Nocturnal hours, belonging to "Sector D. Restricted Intermediate Noise: Areas with commercial permitted uses, such as shopping centers, warehouses, premises or commercial facilities, workshops of automotive and industrial mechanics, sports and recreational centers, gyms, restaurants, bars, taverns, nightclubs, bingo halls, casinos.

- Point 3: 65dB (A) in the Day time period and 50dB (A) in Nocturnal hours, belonging to "Sector B. Tranquility and Moderate Noise: Residential areas or exclusively destined for housing development, hotels and lodgings.", Of the same resolution.

- Point 4: 55dB (A) in the Day time period and 45dB (A) in Nocturnal hours, belonging to "Sector D. Suburban or Rural Zone of Tranquility and Moderate Noise: Suburban Residential.

Figure No. 5.283 shows the identification of the different cadastral blocks in the urban area of the District of Nueva Colonia.

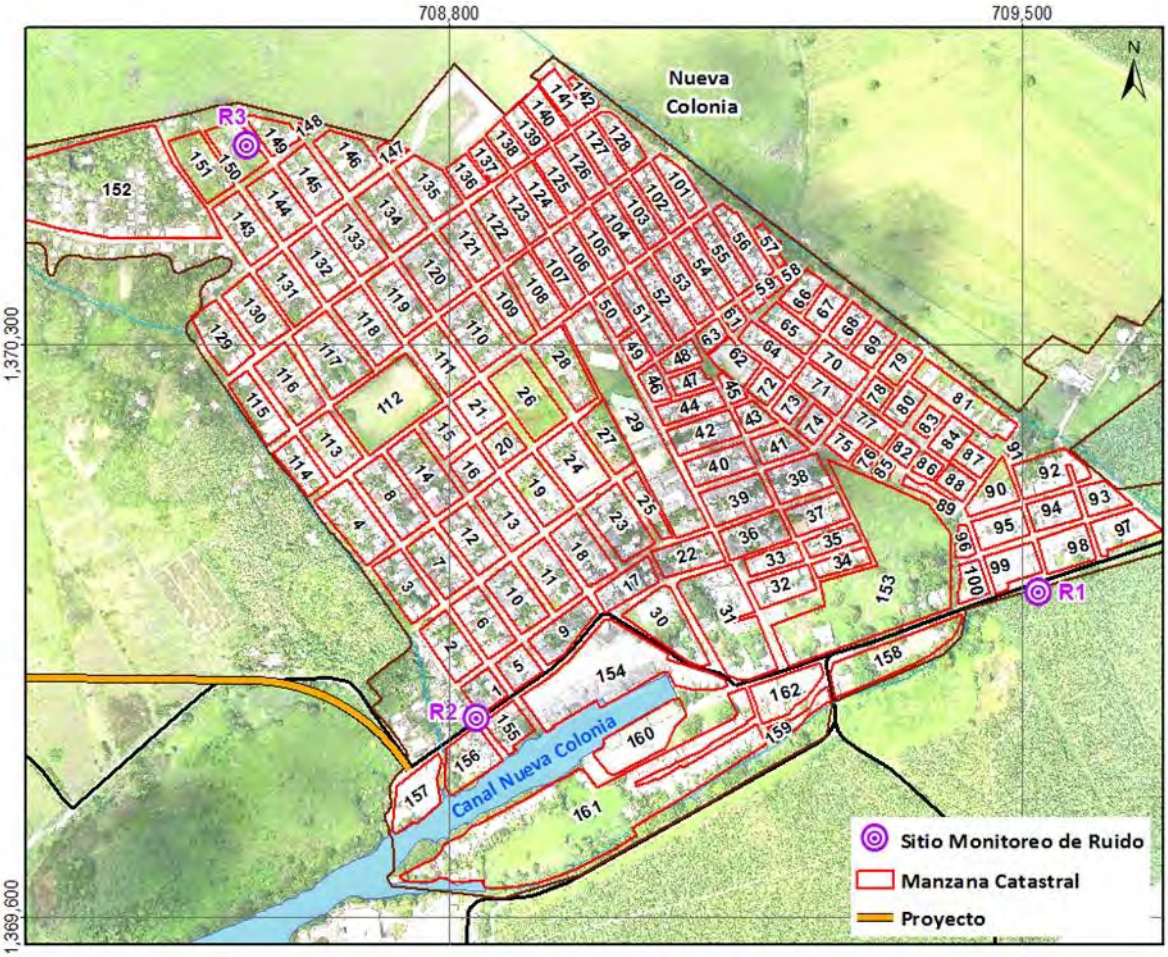


Figure No. 5.262 Identification of Cadastral Blocks and noise measurement points
Source: Aqua & Terra Consultores Asociados S.A.S., 2015

Table No. 5.119 shows the values calculated by CadnaA (Level Leq (A)), the maximum value allowed by current regulations (Limit Value) and the difference between the value calculated by CadnaA and the permissible limit (Excess Level)), for each of the two scenarios (SC1 and SC2); in which the cells are classified with three different colors as indicated in Table No. 5.118.

Table No. 5.103 Color Classification of the levels of excess sound pressure

	Indicates a negative difference of more than 10 dBA, that is to say that there is no risk whatsoever for the dwelling in question.

	Indicates that households that register a difference between -10 and -0.1 dBA. are receiving points that do not exceed the limit levels but may require attention.
	It indicates the houses that present excess of the limit levels established by the standard.

Source: SGS Colombia S.A., 2015

In Table No. 5.118 the range of 10 dB below the norm is taken (yellow houses) due to the mathematical process there is a range of uncertainty, which in the present case is due to the accuracy of the input data in general. Therefore, the manufacturer recommends adding 10 dB to the regulations to be applied to be able to affirm that there is not nor will be any impact due to noise pollution.

Table No. 5.104 Comparison of Sound Pressure Level by cadastral blocks for the scenarios 1 y 2 (SC1 y SC2)

Cadastral Block ID	SC1		SC2		Limit level		SC1		SC2		Coordinates		Height
	Leq Level		Leq Level				Excess Level		Excess Level				
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_01	71,6	71,7	60,1	61,6	70	55	1,6	16,7	-9,9	6,6	708.842	1.369.875	8
M_02	55,2	56,1	60,2	61,8	70	55	-14,8	1,1	-9,8	6,8	708.802	1.369.930	8
M_03	51,9	53,3	59,7	61,3	70	55	-18,1	-1,7	-10,3	6,3	708.746	1.370.003	8
M_04	49,0	50,9	57,8	59,7	70	55	-21,0	-4,1	-12,2	4,7	708.685	1.370.082	8
M_05	71,3	71,4	52,1	54,6	70	55	1,3	16,4	-17,9	-0,4	708.884	1.369.904	8
M_06	44,7	45,4	51,7	54,4	70	55	-25,3	-9,6	-18,3	-0,6	708.841	1.369.959	8
M_07	41,8	43,8	49,7	52,5	70	55	-28,2	-11,2	-20,3	-2,5	708.787	1.370.032	8
M_08	41,7	44,2	47,4	50,1	70	55	-28,3	-10,8	-22,6	-4,9	708.729	1.370.113	8
M_09	70,5	70,5	51,5	54,4	70	55	0,5	15,5	-18,5	-0,6	708.938	1.369.948	8
M_10	44,5	45,4	51,2	54,0	70	55	-25,5	-9,6	-18,8	-1,0	708.881	1.369.989	8
M_11	48,9	49,4	50,0	52,9	70	55	-21,1	-5,6	-20,0	-2,1	708.922	1.370.018	8
M_12	40,4	42,9	49,0	51,8	70	55	-29,6	-12,1	-21,0	-3,2	708.828	1.370.061	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_13	40,2	42,6	48,5	51,3	70	55	-29,8	-12,4	-21,5	-3,7	708.869	1.370.091	8
M_14	41,5	44,2	47,8	50,5	70	55	-28,5	-10,8	-22,2	-4,5	708.769	1.370.142	8
M_15	40,6	43,4	49,0	51,9	70	55	-29,4	-11,6	-21,0	-3,1	708.794	1.370.192	8
M_16	41,2	44,0	49,5	52,4	70	55	-28,8	-11,0	-20,5	-2,6	708.828	1.370.148	8
M_17	68,9	69,0	49,8	52,7	70	55	-1,1	14,0	-20,2	-2,3	709.017	1.370.005	8
M_18	49,6	50,0	49,0	51,8	70	55	-20,4	-5,0	-21,0	-3,2	708.962	1.370.047	8
M_19	39,7	42,0	47,3	50,2	70	55	-30,3	-13,0	-22,7	-4,8	708.909	1.370.121	8
M_20	39,9	42,7	48,0	50,9	70	55	-30,1	-12,3	-22,0	-4,1	708.866	1.370.176	8
M_21	40,9	43,7	48,9	51,8	70	55	-29,1	-11,3	-21,1	-3,2	708.835	1.370.221	8
M_22	48,8	50,3	46,3	49,2	70	55	-21,2	-4,7	-23,7	-5,8	709.091	1.370.041	8
M_23	41,3	43,7	48,2	51,1	70	55	-28,7	-11,3	-21,8	-3,9	709.007	1.370.080	8
M_24	37,6	40,4	46,6	49,5	70	55	-32,4	-14,6	-23,4	-5,5	708.952	1.370.154	8
M_25	40,4	42,8	47,9	50,8	70	55	-29,6	-12,2	-22,1	-4,2	709.041	1.370.102	8
M_26	39,3	42,1	48,9	51,8	70	55	-30,7	-12,9	-21,1	-3,2	708.894	1.370.233	8
M_27	37,8	40,4	46,4	49,4	70	55	-32,2	-14,6	-23,6	-5,6	708.992	1.370.185	8
M_28	39,5	42,4	48,7	51,6	70	55	-30,5	-12,6	-21,3	-3,4	708.941	1.370.271	8
M_29	38,3	41,1	48,0	50,9	70	55	-31,7	-13,9	-22,0	-4,1	709.026	1.370.203	8
M_30	72,4	72,4	50,3	53,2	70	55	2,4	17,4	-19,7	-1,8	709.066	1.369.956	8
M_31	73,0	73,1	47,9	50,7	70	55	3,0	18,1	-22,1	-4,3	709.113	1.370.020	8
M_32	56,3	57,3	46,4	49,4	70	55	-13,7	2,3	-23,6	-5,6	709.206	1.370.003	8
M_33	42,1	43,3	47,0	50,0	70	55	-27,9	-11,7	-23,0	-5,0	709.195	1.370.036	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_34	56,2	57,3	44,6	47,5	70	55	-13,8	2,3	-25,4	-7,5	709.279	1.370.032	8
M_35	48,3	49,6	45,1	48,0	70	55	-21,7	-5,4	-24,9	-7,0	709.266	1.370.060	8
M_36	41,8	43,8	45,9	48,8	70	55	-28,2	-11,2	-24,1	-6,2	709.172	1.370.066	8
M_37	45,8	47,4	45,4	48,3	70	55	-24,2	-7,6	-24,6	-6,7	709.248	1.370.091	8
M_38	42,7	44,7	45,6	48,5	70	55	-27,3	-10,3	-24,4	-6,5	709.226	1.370.135	8
M_39	39,4	41,8	47,6	50,5	70	55	-30,6	-13,2	-22,4	-4,5	709.150	1.370.110	8
M_40	38,6	41,2	47,5	50,5	70	55	-31,4	-13,8	-22,5	-4,5	709.129	1.370.152	8
M_41	38,1	40,6	45,9	48,8	70	55	-31,9	-14,4	-24,1	-6,2	709.199	1.370.175	8
M_42	38,5	41,2	47,5	50,4	70	55	-31,5	-13,8	-22,5	-4,6	709.111	1.370.191	8
M_43	37,5	40,1	45,8	48,7	70	55	-32,5	-14,9	-24,2	-6,3	709.171	1.370.211	8
M_44	38,1	40,9	47,4	50,4	70	55	-31,9	-14,1	-22,6	-4,6	709.094	1.370.223	8
M_45	37,3	40,1	46,0	49,0	70	55	-32,7	-14,9	-24,0	-6,0	709.144	1.370.244	8
M_46	38,2	41,0	47,4	50,3	70	55	-31,8	-14,0	-22,6	-4,7	709.050	1.370.251	8
M_47	37,2	40,0	46,0	48,9	70	55	-32,8	-15,0	-24,0	-6,1	709.093	1.370.254	8
M_48	39,6	42,5	46,4	49,3	70	55	-30,4	-12,5	-23,6	-5,7	709.083	1.370.283	8
M_49	38,1	40,9	47,2	50,2	70	55	-31,9	-14,1	-22,8	-4,8	709.027	1.370.292	8
M_50	37,5	40,3	46,7	49,7	70	55	-32,5	-14,7	-23,3	-5,3	708.998	1.370.338	8
M_51	36,8	39,6	45,1	48,0	70	55	-33,2	-15,4	-24,9	-7,0	709.036	1.370.335	8
M_52	37,2	40,1	45,0	47,9	70	55	-32,8	-14,9	-25,0	-7,1	709.062	1.370.354	8
M_53	37,1	40,0	44,1	47,0	70	55	-32,9	-15,0	-25,9	-8,0	709.085	1.370.373	8
M_54	38,0	40,9	44,2	47,2	70	55	-32,0	-14,1	-25,8	-7,8	709.109	1.370.391	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_55	38,4	41,3	43,8	46,7	70	55	-31,6	-13,7	-26,2	-8,3	709.133	1.370.408	8
M_56	38,9	41,8	44,3	47,3	70	55	-31,1	-13,2	-25,7	-7,7	709.159	1.370.423	8
M_57	39,1	42,0	43,9	46,9	70	55	-30,9	-13,0	-26,1	-8,1	709.191	1.370.421	8
M_58	38,7	41,6	42,7	45,6	70	55	-31,3	-13,4	-27,3	-9,4	709.216	1.370.387	8
M_59	39,1	41,9	43,0	45,9	70	55	-30,9	-13,1	-27,0	-9,1	709.194	1.370.370	8
M_60	38,8	41,6	43,8	46,7	70	55	-31,2	-13,4	-26,2	-8,3	709.170	1.370.351	8
M_61	38,2	41,0	44,2	47,2	70	55	-31,8	-14,0	-25,8	-7,8	709.147	1.370.331	8
M_62	37,6	40,4	45,9	48,9	70	55	-32,4	-14,6	-24,1	-6,1	709.147	1.370.277	8
M_63	36,8	39,5	45,0	47,9	70	55	-33,2	-15,5	-25,0	-7,1	709.119	1.370.309	8
M_64	38,7	41,5	45,2	48,1	70	55	-31,3	-13,5	-24,8	-6,9	709.191	1.370.292	8
M_65	39,3	42,2	44,3	47,3	70	55	-30,7	-12,8	-25,7	-7,7	709.215	1.370.319	8
M_66	38,5	41,4	43,8	46,7	70	55	-31,5	-13,6	-26,2	-8,3	709.230	1.370.363	8
M_67	38,9	41,8	44,1	47,0	70	55	-31,1	-13,2	-25,9	-8,0	709.258	1.370.343	8
M_68	38,9	41,7	43,9	46,8	70	55	-31,1	-13,3	-26,1	-8,2	709.288	1.370.322	8
M_69	38,9	41,7	43,8	46,7	70	55	-31,1	-13,3	-26,2	-8,3	709.316	1.370.299	8
M_70	36,6	39,1	44,4	47,3	70	55	-33,4	-15,9	-25,6	-7,7	709.275	1.370.273	8
M_71	38,6	41,4	44,8	47,8	70	55	-31,4	-13,6	-25,2	-7,2	709.254	1.370.245	8
M_72	39,5	42,2	45,6	48,5	70	55	-30,5	-12,8	-24,4	-6,5	709.186	1.370.248	8
M_73	40,7	43,4	45,4	48,4	70	55	-29,3	-11,6	-24,6	-6,6	709.215	1.370.226	8
M_74	42,1	44,4	45,2	48,1	70	55	-27,9	-10,6	-24,8	-6,9	709.244	1.370.202	8
M_75	45,3	47,5	44,8	47,7	70	55	-24,7	-7,5	-25,2	-7,3	709.281	1.370.179	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_76	46,6	48,6	44,6	47,5	70	55	-23,4	-6,4	-25,4	-7,5	709.308	1.370.161	8
M_77	37,3	40,0	44,4	47,3	70	55	-32,7	-15,0	-25,6	-7,7	709.312	1.370.201	8
M_78	36,7	39,4	44,0	46,9	70	55	-33,3	-15,6	-26,0	-8,1	709.321	1.370.240	8
M_79	38,6	41,3	43,5	46,4	70	55	-31,4	-13,7	-26,5	-8,6	709.349	1.370.277	8
M_80	40,2	42,9	43,6	46,6	70	55	-29,8	-12,1	-26,4	-8,4	709.355	1.370.226	8
M_81	40,5	43,1	43,0	46,0	70	55	-29,5	-11,9	-27,0	-9,0	709.428	1.370.230	8
M_82	45,2	47,4	43,7	46,6	70	55	-24,8	-7,6	-26,3	-8,4	709.354	1.370.169	8
M_83	39,0	41,4	43,4	46,3	70	55	-31,0	-13,6	-26,6	-8,7	709.384	1.370.204	8
M_84	38,2	40,5	43,3	46,2	70	55	-31,8	-14,5	-26,7	-8,8	709.411	1.370.184	8
M_85	48,0	49,9	44,3	47,1	70	55	-22,0	-5,1	-25,7	-7,9	709.330	1.370.147	8
M_86	39,2	41,2	43,6	46,5	70	55	-30,8	-13,8	-26,4	-8,5	709.383	1.370.149	8
M_87	41,8	43,7	42,0	44,9	70	55	-28,2	-11,3	-28,0	-10,1	709.439	1.370.159	8
M_88	49,5	51,3	43,3	46,3	70	55	-20,5	-3,7	-26,7	-8,7	709.418	1.370.130	8
M_89	50,6	52,2	43,9	46,7	70	55	-19,4	-2,8	-26,1	-8,3	709.383	1.370.119	8
M_90	47,9	49,7	42,9	45,8	70	55	-22,1	-5,3	-27,1	-9,2	709.464	1.370.120	8
M_91	40,1	42,6	42,1	45,0	70	55	-29,9	-12,4	-27,9	-10,0	709.488	1.370.168	8
M_92	44,7	46,3	42,0	44,9	70	55	-25,3	-8,7	-28,0	-10,1	709.531	1.370.142	8
M_93	52,6	53,4	41,1	44,1	70	55	-17,4	-1,6	-28,9	-10,9	709.595	1.370.111	8
M_94	47,6	48,2	42,0	44,9	70	55	-22,4	-6,8	-28,0	-10,1	709.538	1.370.095	8
M_95	48,1	48,7	42,9	45,8	70	55	-21,9	-6,3	-27,1	-9,2	709.472	1.370.074	8
M_96	55,6	56,5	43,1	46,0	70	55	-14,4	1,5	-26,9	-9,0	709.428	1.370.056	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_97	73,7	73,8	41,0	43,9	70	55	3,7	18,8	-29,0	-11,1	709.620	1.370.073	8
M_98	73,5	73,6	41,8	44,8	70	55	3,5	18,6	-28,2	-10,2	709.553	1.370.049	8
M_99	75,1	75,2	42,1	45,0	70	55	5,1	20,2	-27,9	-10,0	709.486	1.370.029	8
M_100	72,0	72,2	43,0	45,8	70	55	2,0	17,2	-27,0	-9,2	709.437	1.370.009	8
M_101	38,3	41,1	44,4	47,3	70	55	-31,7	-13,9	-25,6	-7,7	709.081	1.370.492	8
M_102	37,8	40,7	44,5	47,5	70	55	-32,2	-14,3	-25,5	-7,5	709.055	1.370.478	8
M_103	37,3	40,2	44,5	47,4	70	55	-32,7	-14,8	-25,5	-7,6	709.031	1.370.459	8
M_104	37,1	40,0	45,1	48,1	70	55	-32,9	-15,0	-24,9	-6,9	709.006	1.370.441	8
M_105	36,7	39,6	45,4	48,3	70	55	-33,3	-15,4	-24,6	-6,7	708.982	1.370.422	8
M_106	36,7	39,6	45,4	48,4	70	55	-33,3	-15,4	-24,6	-6,6	708.958	1.370.404	8
M_107	36,9	39,7	45,6	48,6	70	55	-33,1	-15,3	-24,4	-6,4	708.933	1.370.386	8
M_108	38,3	41,2	47,3	50,3	70	55	-31,7	-13,8	-22,7	-4,7	708.905	1.370.365	8
M_109	39,3	42,2	48,4	51,3	70	55	-30,7	-12,8	-21,6	-3,7	708.872	1.370.344	8
M_110	39,3	42,2	48,7	51,6	70	55	-30,7	-12,8	-21,3	-3,4	708.834	1.370.314	8
M_111	40,6	43,5	49,9	52,8	70	55	-29,4	-11,5	-20,1	-2,2	708.790	1.370.281	8
M_112	40,8	43,7	48,6	51,5	70	55	-29,2	-11,3	-21,4	-3,5	708.724	1.370.226	8
M_113	41,2	44,0	48,6	51,3	70	55	-28,8	-11,0	-21,4	-3,7	708.655	1.370.177	8
M_114	46,3	48,6	55,7	57,9	70	55	-23,7	-6,4	-14,3	2,9	708.618	1.370.150	8
M_115	44,6	47,0	54,2	56,6	70	55	-25,4	-8,0	-15,8	1,6	708.566	1.370.221	8
M_116	39,0	41,8	47,4	50,3	70	55	-31,0	-13,2	-22,6	-4,7	708.605	1.370.250	8
M_117	41,1	44,1	50,4	53,4	70	55	-28,9	-10,9	-19,6	-1,6	708.655	1.370.286	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_118	40,9	43,9	50,0	53,0	70	55	-29,1	-11,1	-20,0	-2,0	708.700	1.370.322	8
M_119	40,2	43,1	49,4	52,3	70	55	-29,8	-11,9	-20,6	-2,7	708.737	1.370.354	8
M_120	39,4	42,3	48,9	51,8	70	55	-30,6	-12,7	-21,1	-3,2	708.782	1.370.387	8
M_121	38,7	41,6	47,9	50,8	70	55	-31,3	-13,4	-22,1	-4,2	708.824	1.370.419	8
M_122	37,9	40,8	47,2	50,2	70	55	-32,1	-14,2	-22,8	-4,8	708.859	1.370.444	8
M_123	36,7	39,6	46,2	49,1	70	55	-33,3	-15,4	-23,8	-5,9	708.886	1.370.463	8
M_124	36,6	39,6	45,9	48,8	70	55	-33,4	-15,4	-24,1	-6,2	708.911	1.370.481	8
M_125	37,0	39,8	45,7	48,7	70	55	-33,0	-15,2	-24,3	-6,3	708.935	1.370.499	8
M_126	36,4	39,3	44,9	47,8	70	55	-33,6	-15,7	-25,1	-7,2	708.959	1.370.517	8
M_127	36,9	39,7	44,6	47,6	70	55	-33,1	-15,3	-25,4	-7,4	708.984	1.370.534	8
M_128	37,0	39,9	43,5	46,5	70	55	-33,0	-15,1	-26,5	-8,5	709.009	1.370.549	8
M_129	42,8	45,3	52,1	54,6	70	55	-27,2	-9,7	-17,9	-0,4	708.522	1.370.307	8
M_130	41,0	43,9	50,2	53,1	70	55	-29,0	-11,1	-19,8	-1,9	708.563	1.370.339	8
M_131	39,2	42,1	49,1	52,1	70	55	-30,8	-12,9	-20,9	-2,9	708.603	1.370.366	8
M_132	40,3	43,2	49,4	52,4	70	55	-29,7	-11,8	-20,6	-2,6	708.644	1.370.397	8
M_133	39,7	42,6	48,8	51,7	70	55	-30,3	-12,4	-21,2	-3,3	708.684	1.370.427	8
M_134	39,0	41,9	48,1	51,1	70	55	-31,0	-13,1	-21,9	-3,9	708.728	1.370.460	8
M_135	38,2	41,1	47,3	50,2	70	55	-31,8	-13,9	-22,7	-4,8	708.775	1.370.491	8
M_136	37,9	40,8	46,5	49,4	70	55	-32,1	-14,2	-23,5	-5,6	708.820	1.370.504	8
M_137	37,0	39,8	45,4	48,3	70	55	-33,0	-15,2	-24,6	-6,7	708.846	1.370.523	8
M_138	37,2	40,1	45,2	48,1	70	55	-32,8	-14,9	-24,8	-6,9	708.869	1.370.543	8

Cadastral Block ID	SC1 Leq Level		SC2 Leq Level		Limit level		SC1 Excess Level		SC2 Excess Level		Coordinates		Height
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	X	Y	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dB)	(dB)	(dB)	(dB)	(m)	(m)	(m)
Nueva Colonia													
M_139	36,6	39,5	44,8	47,7	70	55	-33,4	-15,5	-25,2	-7,3	708.892	1.370.561	8
M_140	37,0	39,9	44,5	47,5	70	55	-33,0	-15,1	-25,5	-7,5	708.916	1.370.581	8
M_141	36,7	39,7	43,8	46,8	70	55	-33,3	-15,3	-26,2	-8,2	708.939	1.370.600	8
M_142	36,5	39,4	43,8	46,8	70	55	-33,5	-15,6	-26,2	-8,2	708.964	1.370.604	8
M_143	40,3	43,2	49,4	52,3	70	55	-29,7	-11,8	-20,6	-2,7	708.550	1.370.441	8
M_144	39,3	42,3	48,4	51,4	70	55	-30,7	-12,7	-21,6	-3,6	708.591	1.370.469	8
M_145	39,0	41,9	48,0	50,9	70	55	-31,0	-13,1	-22,0	-4,1	708.630	1.370.500	8
M_146	38,3	41,2	47,4	50,3	70	55	-31,7	-13,8	-22,6	-4,7	708.675	1.370.527	8
M_147	37,9	40,7	46,6	49,6	70	55	-32,1	-14,3	-23,4	-5,4	708.728	1.370.534	8
M_148	37,8	40,7	46,7	49,6	70	55	-32,2	-14,3	-23,3	-5,4	708.627	1.370.564	8
M_149	38,3	41,2	47,2	50,2	70	55	-31,7	-13,8	-22,8	-4,8	708.585	1.370.557	8
M_150	38,8	41,7	47,8	50,7	70	55	-31,2	-13,3	-22,2	-4,3	708.540	1.370.537	8
M_151	38,7	41,7	47,7	50,6	70	55	-31,3	-13,3	-22,3	-4,4	708.497	1.370.517	8
M_152	40,9	43,6	49,6	52,2	70	55	-29,1	-11,4	-20,4	-2,8	708.454	1.370.482	8

Source: SGS Colombia S.A., 2015

The levels in Table No. 5.119 refer to the highest levels found in any of the facades of each block, because CadnaA automatically takes the highest value in some of the sides of the polygon that represents a facade. Generally, the sides with higher levels correspond to those that are directly exposed to the emission of noise, but the adjacent and later sides will tend to have lower levels of sound pressure.

❖ Comparison of the levels measured with the calculated levels

To compare the sound pressure levels recorded at ambient noise measurement points with the levels calculated by the CadnaA acoustic prediction model, it must be considered that the noise captured in the measurements can correspond to a number of sources that have nothing to see with the operation activities of the sections in each scenario. However, the comparison is made in order to draw some conclusions as a reference.

For this process, the maximum values measured are taken, without discriminating whether the measurements were on a working or non-working day in order to represent the most critical scenario as shown in Table No. 5.120.

Table No. 5.105 Comparison of calculated sound pressure levels (CadnaA) vs. Measured levels

Monitoring point ID	SC1				SC2				Height
	Calculated Level		Measured level		Calculated Level		Measured level		
	Leq Level		Leq Level		Leq Level		Leq Level		Height
	Day	Night	Day	Night	Day	Night	Day	Night	H
	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(dBA)	(m)
R1	71,0	71,2	67,8	68,7	41,8	44,7	67,8	68,7	6.33
R2	71,0	71,1	65,4	66,3	58,7	60,4	65,4	66,3	4.90
R3	38,0	41,0	79	67,5	47,2	50,1	79	67,5	4.04
R4	63,8	63,9	49,9	56,9	67,9	68,7	49,9	56,9	5.00

Source: SGS Colombia S.A., 2015

❖ Conclusions

Taking into account the results obtained and the maximum permissible levels established in Article 17 of Resolution 0627 of 2006[297], it can be concluded that:

[297] COLOMBIA. MINISTRY OF ENVIRONMENT, HOUSING AND SUSTAINABLE DEVELOPMENT. Resolution 627 (April 07, 2006). Op cit.

- The noise levels generated by the activities of Scenario I: Operation of existing roads, "Nueva Colonia Puerto Bahia Colombia De Urabá Area", exceeds 70 dB (A) Diurnal, in nine (09) of the hundred and fifty-two (152) receiver points (blocks) calculated within the area of interest.

- The activities of Scenario I: Operation of existing roads, "Nueva Colonia Puerto Bahia Colombia De Urabá", do not generate sound pressure levels that, during a prolonged exposure, can be harmful to the population for a hundred and forty-three (143) of the one hundred and fifty-two (152) receiving points (blocks) calculated within the area of interest, in the Daytime schedule.

- The noise levels generated by the activities of "Scenario I: Operation of existing roads," Nueva Colonia Puerto Bahia Colombia De Urabá Area" exceeds the nocturnal 55 dB (A), in fourteen (14) of the one hundred and fifty two (152) receiving points (blocks) calculated within the area of interest.

- The activities of "Scenario I: Operation of existing roads," Nueva Colonia Puerto Bahia Colombia De Urabá Area", do not generate sound pressure levels that, during a prolonged exposure, can be harmful to the population for one hundred thirty-eight (138) of the one hundred and fifty-two (152) receiving points (blocks) calculated within the area of interest, in the Nocturnal schedule.

- The noise levels generated by the activities of "Scenario II: Operation of projected roads," New Colonia- Puerto Bahía Colombia de Urabá ", do not exceed the diurnal 70 dB (A) in any of the one hundred and fifty-two (152) receiving points (blocks) calculated within the area of interest.

- The noise levels generated by the activities of "Scenario II: Operation of projected roads," New Colonia - Puerto Bahía Colombia De Urabá ", exceed the nocturnal 55 dB (A), in six (06) of the one hundred and fifty two (152) receiving points (blocks) calculated within the area of interest.

- The activities of "Scenario II: Operation of projected roads," New Colonia - Puerto Bahía Colombia de Urabá ", do not generate levels of sound pressure that, during a prolonged exposure, could become harmful to the population for one hundred and forty-six (146) of the one hundred and fifty-two (152) receiving points (blocks) calculated within the area of interest, in the Nocturnal schedule.

- In the case of all the receivers (blocks) of Table No. 5.120 that are in yellow color within the columns called "Excess Value", although they do not exceed the maximum permissible levels, it is recommended to conduct noise monitoring once the corresponding sections become operational, in order to corroborate the results presented in this report and meet the ideal conditions of Equivalent Continuous Sound Pressure Level (Leq). This is due to the 10 dB of uncertainty of different model variables (PWL, climatic conditions, level curves, among others).).

- For Scenario I, the houses that are most affected are those that face the roads in the southern part of the urban area, with sound pressure levels of up to 73 dB (A).

- At a general level, the houses that are most affected by the operation activities of the road projected from Nueva Colonia to Puerto Bahía Colombia De Urabá (Scenario II), are those that face the curvature existing at the beginning of the section that takes a North-western direction with maximum levels of 62 dB (A).

- Because the predictions of vehicular flow in the Traffic Study are not discriminated by day and night shifts, the flows in terms of veh / h are assumed to be equal within the calculation. In reality, it is highly possible that the greatest vehicular activity is present in the daytime hours, which would considerably affect the result, especially at night, generating a much lower level in such scenario.

- The significant differences between the results obtained from the ambient noise of the four (4) monitoring points and the points calculated by the model for Scenario I, indicate that there are different activities to those taken into account for the modeling (only vehicle flow); so it is not correct to make such a comparison.

- From the comparison of the sound pressure levels it can be concluded that the energy contribution in Scenario II will not be considerable since the noise measured in points 1, 2 and 3 exceeds the levels calculated for the same points by means of the acoustic modeling, and that if said measurements were taken as a baseline, when performing a logarithmic sum of decibels, the total would remain equal to the measured levels, so that the noise produced by the operation activities of the projected roads does not influence those points.

- The topographic characteristics of the area in general do not influence the behavior of the propagation of sound waves, as it is a flat area and there are no greater differences of elevations in the evaluated sectors.

It is essential to note that the values of Sound Pressure Level thrown by the model correspond to noise levels only associated with the activities within the Puerto Bahía Colombia De Urabá Port Terminal. This indicates that the acoustic reality of populated areas can have much higher noise levels, due to the activities of its inhabitants and ambient noise.

❖ WaveWatchIII™ MODEL

For the wave action study on the study area it was necessary to analyze the maritime climate based on the results of large-scale physical-mathematical models, because there is no instrumental buoy in the vicinity of the study area. It is clear that the data from the Barranquilla buoy is not sufficient for an adequate analysis of the maritime climate in the study area, due to its short record length, but it is important to note that it allows calibrating the numerical models that are available.

The WaveWatchIII™ model is a third-generation spectral wave model that includes interactions between the atmosphere and the wave fields; the model shows excellent results with typical mean square errors of 15% with respect to the height of observed waves, particularly in tropical regions, presenting poor approximations in high latitudes regions. The model solves the spectral density equation with average properties such as water depth and currents, considering that the wave field varies in time and space much more than a simple wave. The model can be applied at spatial scales from 1 to 10 km and outside the wave breaker zone. The equation that governs the model includes the refraction and diffraction of the wave field, with spatial and temporal variations of the mean depth of water and currents when applied. Physical processes consider the growth and decrease of the wave by wind action. Wave propagation is considered to have a linear behavior, with non-linear effects such as those already mentioned. The program projects wave results such as significant wave height (Hs), direction (θ), frequencies, and spectra, among others.

This is how the WaveWatchIII™ model data was used. The model initially used data from the Pacific Climate Analysis program, which predicted wave data using wind information from the NCEP / NCAR (Kalnay et al., 1996), with data every 6 hours at 10 m. height, where the wind was used as the main forcing. The predicted wave series was calibrated with information from NOAA's oceanographic buoys, National Data Buoy Center (NDBC). The results presented good adjustments, especially in inter-annual variability events, which demonstrated the robustness of the model (Graham and Díaz, 2001).

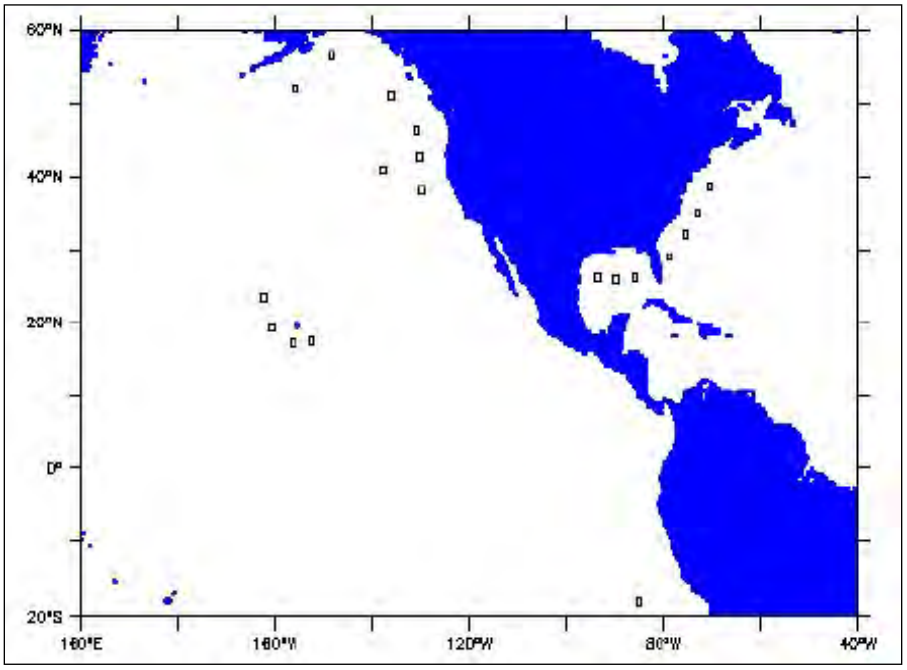


Figure No. 5.263 Location of the NOAA buoys, with whose data the model was calibrated
Source: WaveWatchIII™. Taken from Caires et al (2002).

The available data of the model is spatially distributed over the Colombian Caribbean on a 0.25 ° x0.25 ° mesh (see Figure No. 5.125), the WW_Barranquilla point correspond to the WaveWatchIII™ series that was used to calibrate the data of the model with the data from the Barranquilla buoy, the series located at point WW_GOLFO is the series used to obtain the mean regime at indefinite depths whose temporal resolution is one hour and recorded variables such as Hs, Tp and θ between the years 1999 and 2014.

Figure No. 5.264 Sites with information related to waves from the WaveWatchIII™ project. The point WW_Barranquilla correspond to the series of WaveWatchIII™ that was used to calibrate the data of the model with the data of the Barranquilla buoy and the point WW_GOLFO is the series used to obtain the average regime in indefinite depths.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

❖ Wave Calibration

In order to calibrate the WaveWatchIII™ model data shown in Figure 5.125, the data from the Barranquilla buoy was used. The calibration procedure of the series consisted of the following: 1) We searched for one of the virtual buoys obtained with the WaveWatchIII™ model near the location of the buoys, in this case we worked with the data of the virtual buoy located at 11 ° 15'00 "N 74 ° 45'00" W, 2) Once the model data and buoy data is available, all the data corresponding to the same date in the two series is searched, 3) With the data pairs a linear regression is made between the model data and buoy data, both with the same probability level of non-exceedance, in order to obtain the calibration parameters of the wave series for the

significant wave height and 4) The calibration parameters are applied to the series of WaveWatchIII^{TM} in the Gulf of Urabá.

Figure No. 5.126 compares the WaveWatchIII^{TM} data with the data from the Barranquilla buoy.

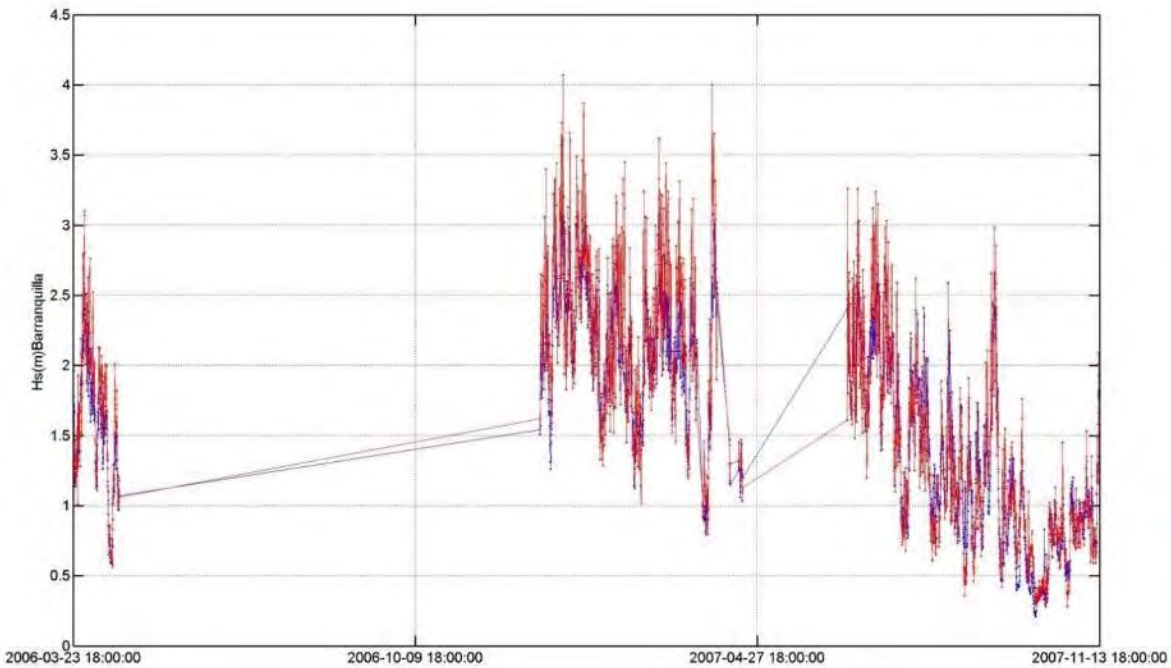


Figure No. 5.265 WaveWatch IVTM model data and data from the Barranquilla buoy for the buoy's registration period (March 23, 2006 to December 1, 2007)).
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

In the previous figure we can see how the data of the model follow the trend of the data of the buoy, but it is also seen that the data of the model underestimate the significant wave height data, it's for this reason that the data of the model have to be calibrated with instrumental data.

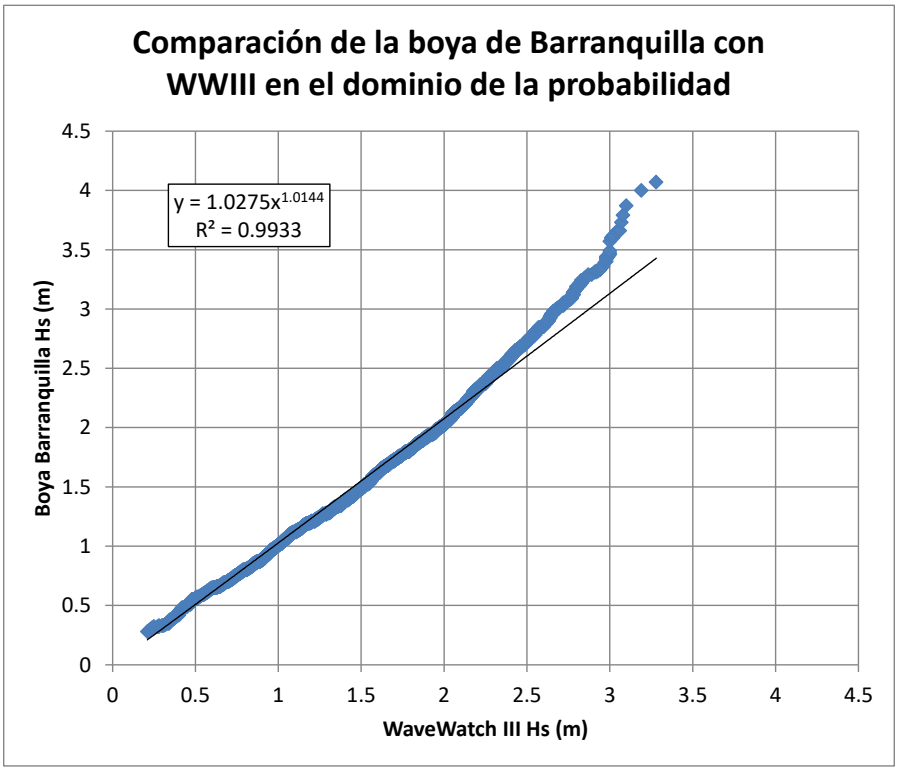


Figure No. 5.266 Relation between the significant wave height of the Barranquilla Buoy and the significant wave height in the virtual buoy obtained by the WaveWatchIII™ model at the 74 ° 45'W-11 ° 15'N point.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

Figure No. 5.127Comparison of the Barranquilla buoy with WWIII in the probability domain

Table No. 5.106 Values of coefficients a and b in the regression a * x ^ b for mean values of Hs.

Significant wave height (Hs)	a	b
Buoy-WWIII	**1.028**	**1.014**

In Figure No. 5.127 it was found that the significant wave height data of the WaveWatchIII™ model underestimated the data measured with the buoys and the calibration parameters of the series were found by means of a regression of the a*x^b type. The parameters obtained in the potential regression are shown in Table No. 5.47, which, due to not having more information, were those used to correct the WaveWatchIII™ data, at the WW_GOLFO point (Figure No. 5.125), starting from which will be the propagation of the waves towards the study area.

Below is a comparison of the periods of the Barranquilla buoy and the periods of the WaveWatchIII™ model.

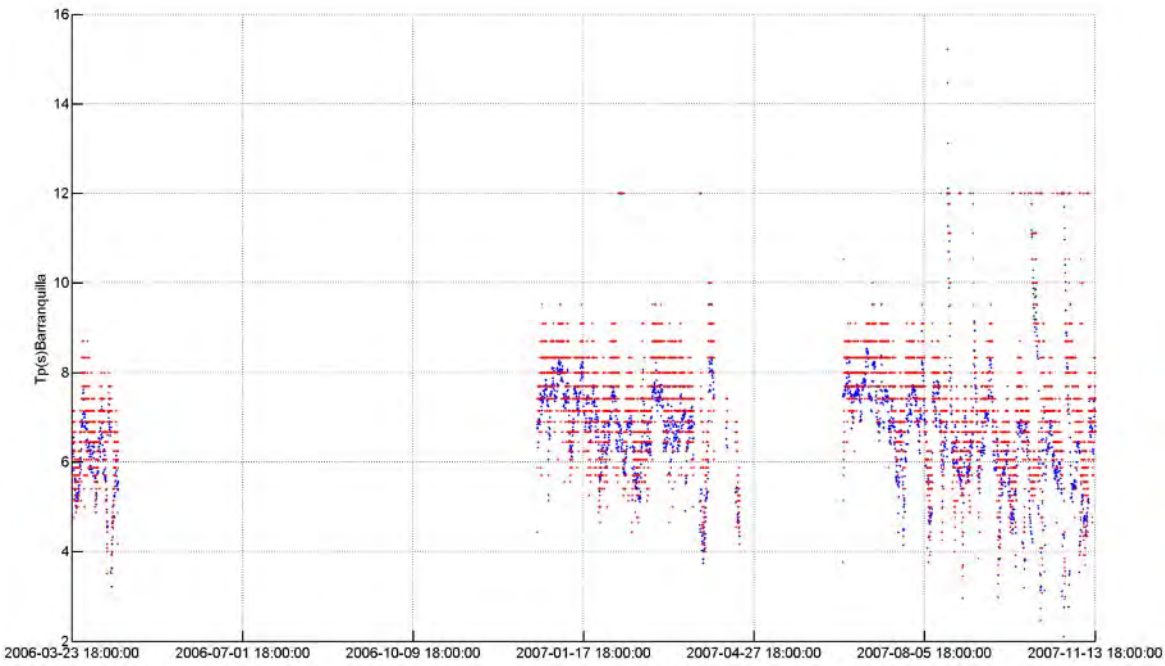


Figure No. 5.267 WaveWatchIII™ model data (red) and data from the Barranquilla buoy (blue) for the buoy's registration period between March 23, 2006 and December 1, 2007.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

The comparison of WaveWatchIII™ model's periods and the periods of the Barranquilla buoy show that the model is following very well the magnitude and the trend of the buoy series, showing the two types of waves (sea and swell) of the same magnitude that occur in the study area, therefore it is not necessary to correct the period data of the model.

- **Medium swell in indefinite depths**

After applying the methodology described above, the coefficients were applied to the series of the model located at the coordinates 9 ° 0'0 "N-77 ° 0'0" W- Below are the most representative graphs of the swell's time series.

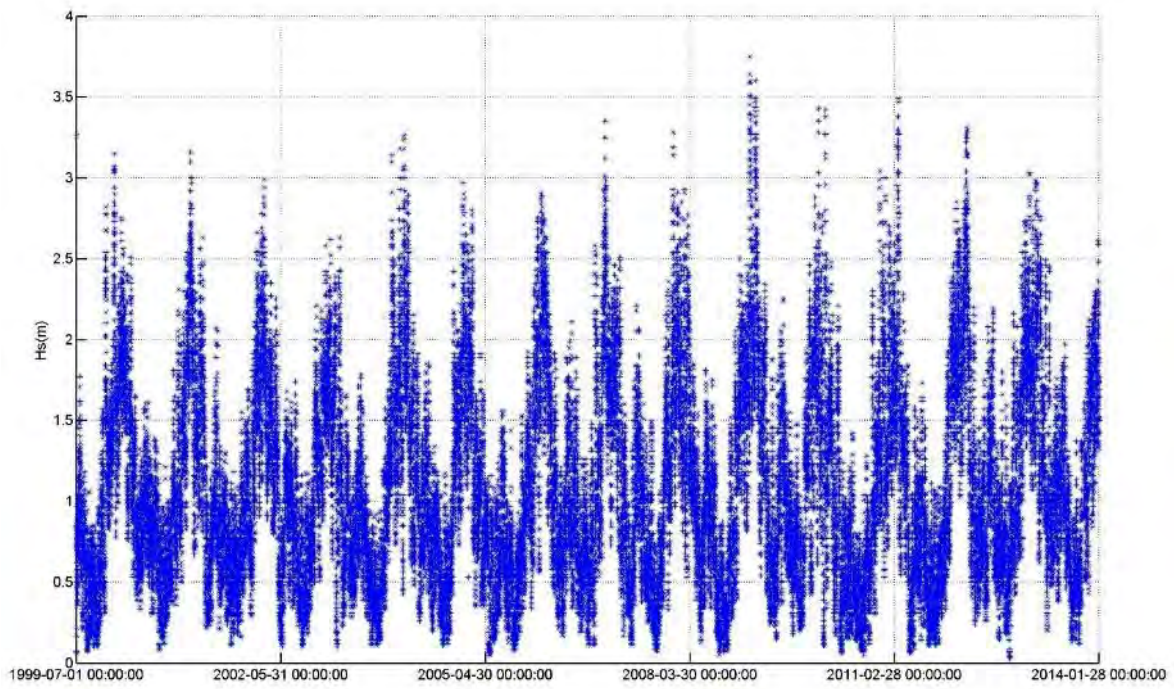


Figure No. 5.268 Corrected data series for Hs, at 9 ° 0'00 "N 77 ° 0'00" W
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

In the previous figure we can see the swell behavior in the WW_GOLFO. It is noted that the peaks of the waves appear in the first months of the year, where you can see waves with a magnitude that exceeds 2.5 m in height, and can even reach more than 3.0 m in height, and in the months of June and July, period for which the summer of San Juan is presented in the Caribbean region, you can see wave heights that exceed 1.5 m in height. In the months of October and November the minimum wave height values in the region are presented.

The waves recorded in the virtual buoy located at the geographic coordinates 9 ° 0'0 "N-77 ° 00'0" W present a length of record of 14 years beginning August 1999 and ending on January 31, 2014, said series is continuous in time with a temporary resolution of three hours.

Regarding the periods we can see that the vast majority are clustered between 4 and 10 seconds, characteristic values throughout the Caribbean basin.

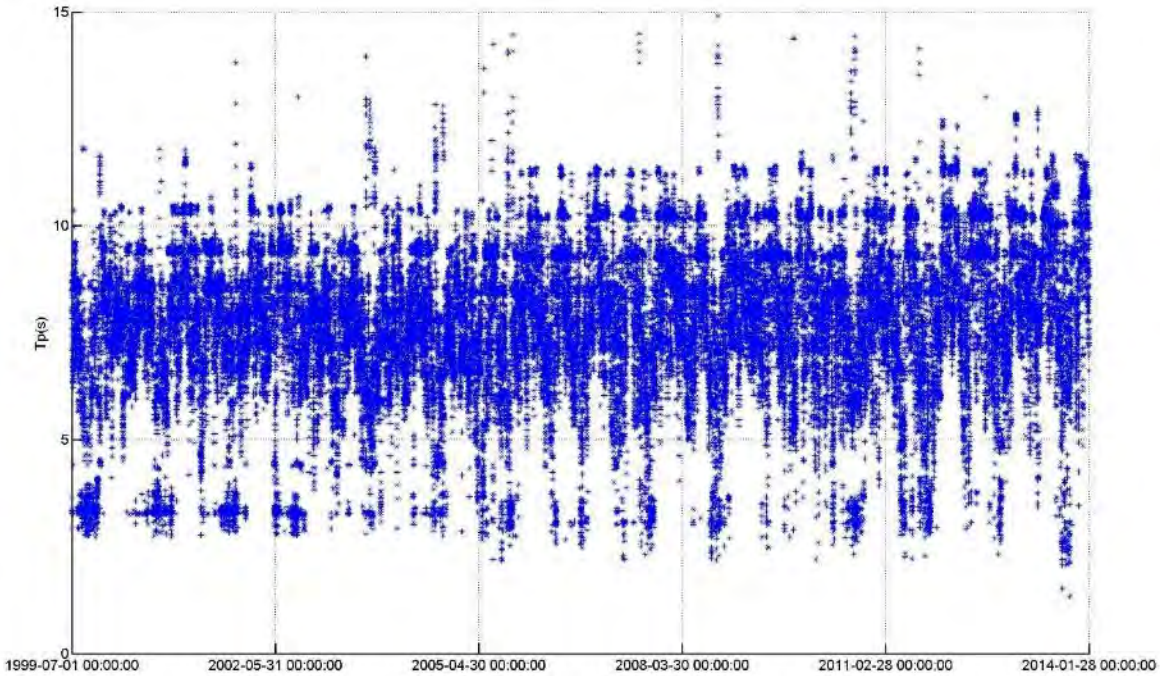


Figure No. 5.269 Corrected data series for Tp, at 9 ° 0'00 "N 77 ° 0'0" W
Source: Aqua & Terra Consultores Asociados S.A.S, 2015

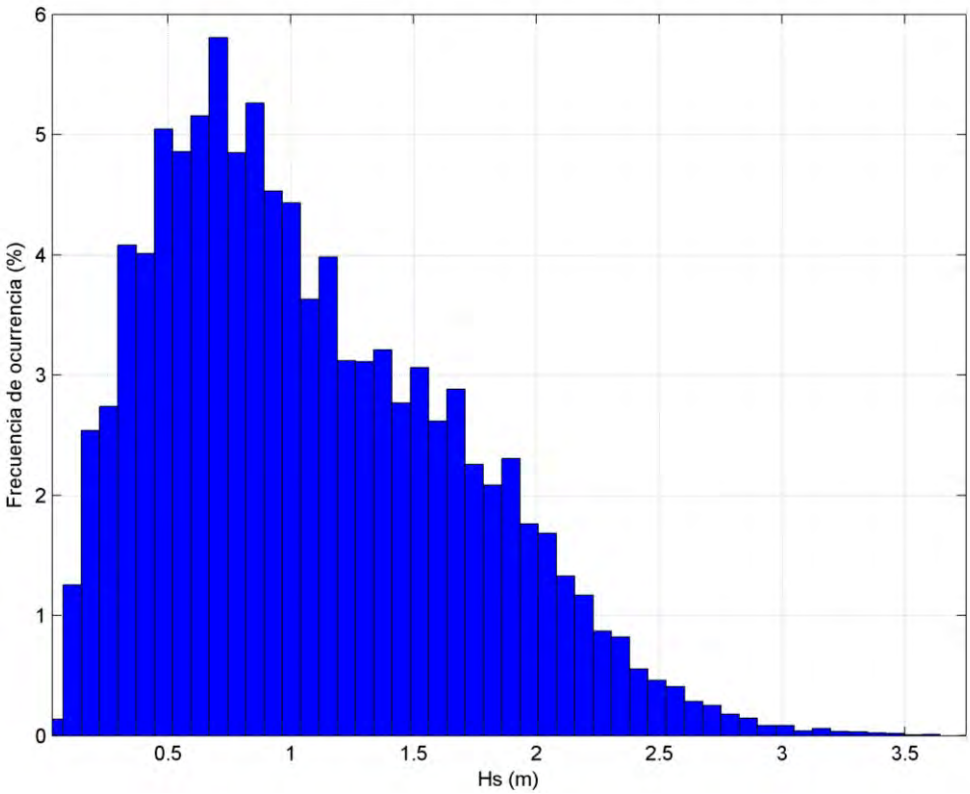


Figure No. 5.270 Frequency histogram for Hs-WaveWatchIII™, 9 ° 0'00 "N 77 ° 0'0" W
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

Figure No. 5.131 Occurrence frequency (%)

The wave height values presented in the series range from the order of centimeters Hsmin = 0.1 m to maximum values that reach Hsmax = 3.5 m, with an average of Hsmed = 1.07 m. In this graph it can be seen that the wave height values have a skewed distribution to the left.

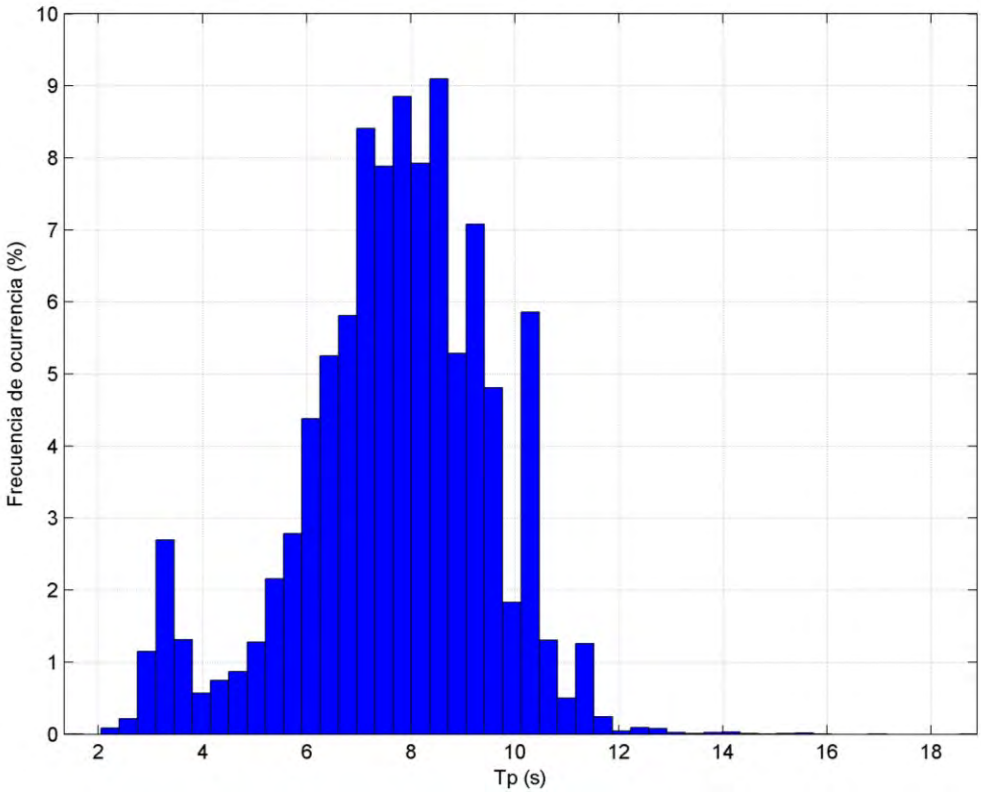


Figure No. 5.271 Frequency histogram for Hs-WaveWatchIII™, 9°0'00"N 77°0'0"W.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

Figure No. 5.131 Occurrence frequency (%)

For the peak periods it is seen how the values are concentrated between 6 and 10. It can be seen that very infrequently they present periods greater than 10 seconds.

The wave rose indicates the direction and height of the waves in deep waters in a wide area in front of the study area. The most frequent waves come from the NNE with a probability of occurrence close to 79% and the NE with a percentage of 10%. These two directions represent 89% of the waves that occur in indefinite depths, for the study area.

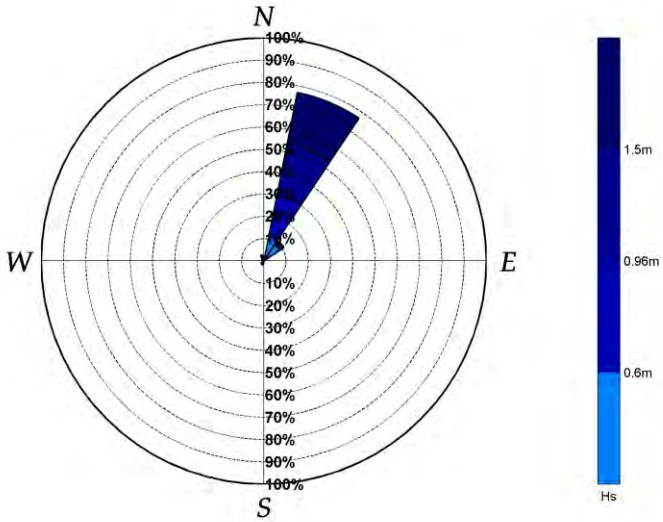


Figure No. 5.272 Wave rose.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

Table No. 5.107 Values of coefficients a and b in the regression a * x ^ b for mean values of

TABLA ESTADISTICOS BASICOS

Variable medida Hs

direcciones(°)	prob direccion	Hs	Hs	Hs	Hs	Hs
ESC	——	0.9600	1.9500	2.1900	2.6600	3.1732
N	0.0208	0.9200	1.8400	2.2800	2.9138	3.3916
NNE	0.7697	1.1400	2.0300	2.2600	2.7100	3.2272
NE	0.1091	0.4300	0.7000	0.7700	0.9500	1.1131
ENE	0.0000	0.5400	0.6700	0.6700	0.6700	0.6700
E	0.0000	0.7000	0.7000	0.7000	0.7000	0.7000
ESE	0.0000	0.4500	0.4500	0.4500	0.4500	0.4500
SE	0.0001	0.4000	1.1700	1.1700	1.1700	1.1700
SSE	0.0008	0.6700	0.9700	1.0725	1.1200	1.1200
S	0.0084	0.6100	0.9200	1.0470	1.1594	1.3300
SSW	0.0176	0.6400	0.9300	1.0120	1.1600	1.3191
SW	0.0147	0.6200	0.9000	0.9800	1.1104	1.2616
WSW	0.0052	0.5150	0.8630	0.9440	1.1684	1.1900
W	0.0012	0.5000	0.9500	0.9990	1.2494	1.2500
WNW	0.0031	0.2400	0.7000	0.8070	1.1240	1.2900
NW	0.0109	0.5600	1.1440	1.5100	2.1778	2.8964
NNW	0.0275	0.6100	1.5890	2.0920	2.7704	2.9890

Hs.b

The basic statistics of the virtual buoy's wave series are presented in Table No. 5.48, where it is important to note that for the NE, ENE directions, the most frequent wave heights are presented, with a joint percentage of 95%.

❖ Wave (local waves by wind) Turbo station winds

Because in the Gulf of Urabá the background swell can be affected when it enters this, and its magnitude can be drastically reduced by refractive and diffraction effects, it was considered to model separate the effect of the wind or local swell to the interior from the Gulf of Urabá. The wind or local swell in geographies such as the Gulf of Urabá and Bahía Colombia, may have more relevance in the background swell. Everything will depend on the configuration of the gulf and the length of development (or FETCH).

To feed a model that converts the wind into swell, the data recorded by the Turbo station, property of the International Station Meteorological Climate Summary (ISMCS), which was located in the Punta Las Vacas sector in the Municipality of Turbo, Antioquia, was used. , and has records between January 1949 and May 1984. The information available from this station is not the time series of wind magnitude and direction but the wind occurrence probability statistics during the entire recording period by intervals of magnitude for the 16 main directions (Table No. 5.49). The wind and wave directions indicate where it comes from.

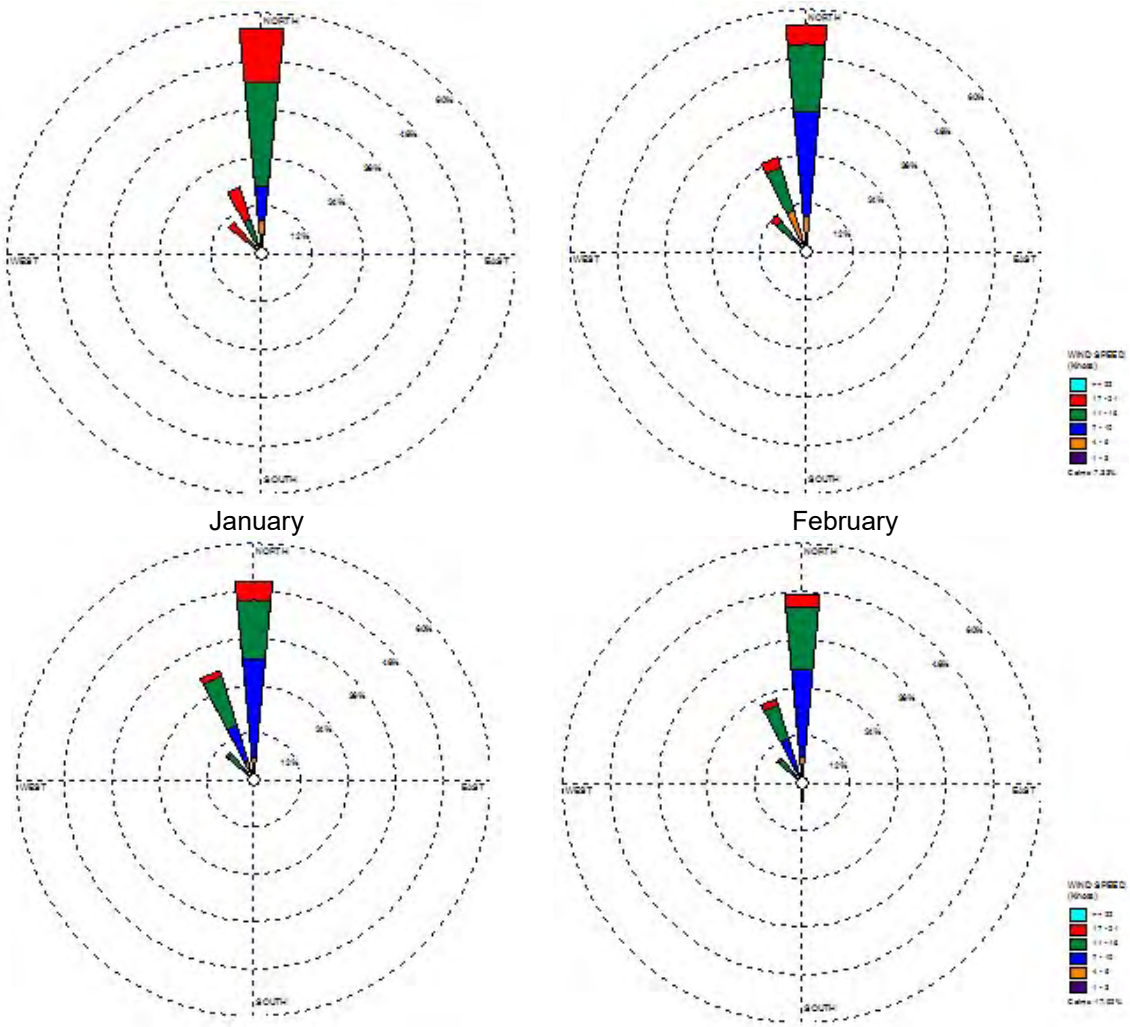
Table No. 5.108 Turbo station information of wind occurrence probability.

Speed intervals. wind (m / s)	0.5 – 3.5	3.5 – 6	6 – 9.5	9.5 – 14.5	14.5 - 18.5	18.5 – 23.5	Total% per direction
N	0.4	3.6	11.6	5.6	0.7	0	21.8
NNE	0.1	0.2	0	0	0	0	0.4
NE	0.2	0.2	0.1	0	0	0	0.5
ENE	0	0	0	0	0	0	0.1
E	0.3	0.4	0.1	0	0	0	0.8
ESE	0	0.1	0.1	0	0	0	0.2
SE	0.2	0.5	0.2	0	0	0	0.9
SSE	0.2	0.7	0.2	0.1	0	0	1.2
S	0.9	6	8.5	1.1	0.1	0	16.6
SSW	0.3	1	0.6	0.1	0	0	2
SW	0.3	2.4	2.5	0.3	0	0	5.5
WSW	0.1	0.6	0.2	0	0	0	1
W	0.5	1.4	0.5	0.1	0	0	2.5
WNW	0	0.3	0.1	0.1	0	0	0.7
NW	0.2	1.8	3.3	1.9	0.3	0.1	7.6
NNW	0.2	1.8	3.4	3.4	0.4	0.1	9.4
Calm Periods(%)							28.7

Speed intervals. wind (m / s)	0.5 – 3.5	3.5 – 6	6 – 9.5	9.5 – 14.5	14.5 - 18.5	18.5 – 23.5	Total% per direction
sum of the percentages of each direction plus calm periods							100

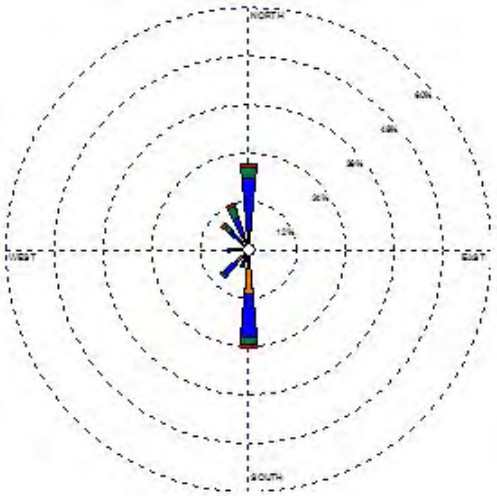
Source:Aqua&Terra Consultores asociados S.A.S, 2015 .

Figure No. 5.134 shows the multi-year average winds in direction and frequency according to the speed in m / s of the Turbo station between January 1949 and May 1984. The figure shows the direction from where the winds reach the point where the measuring station is at.

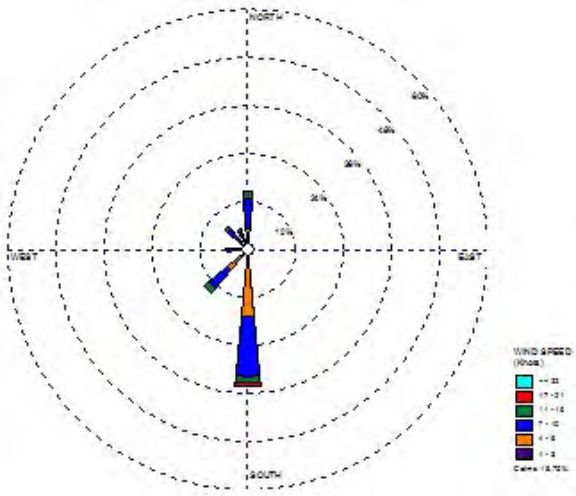


January February

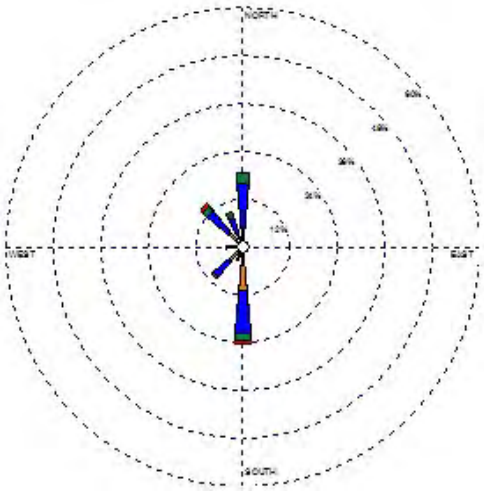
March April



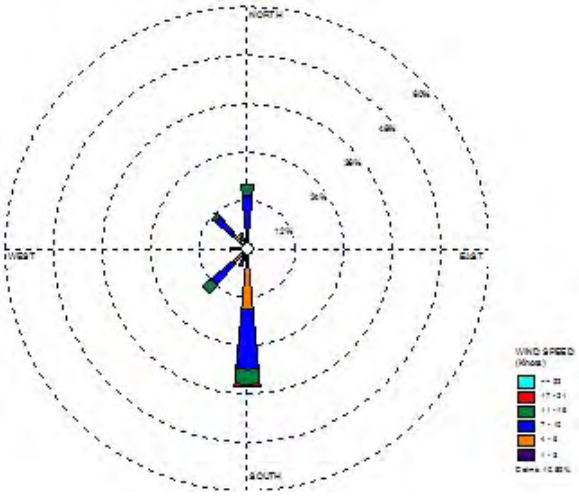
May



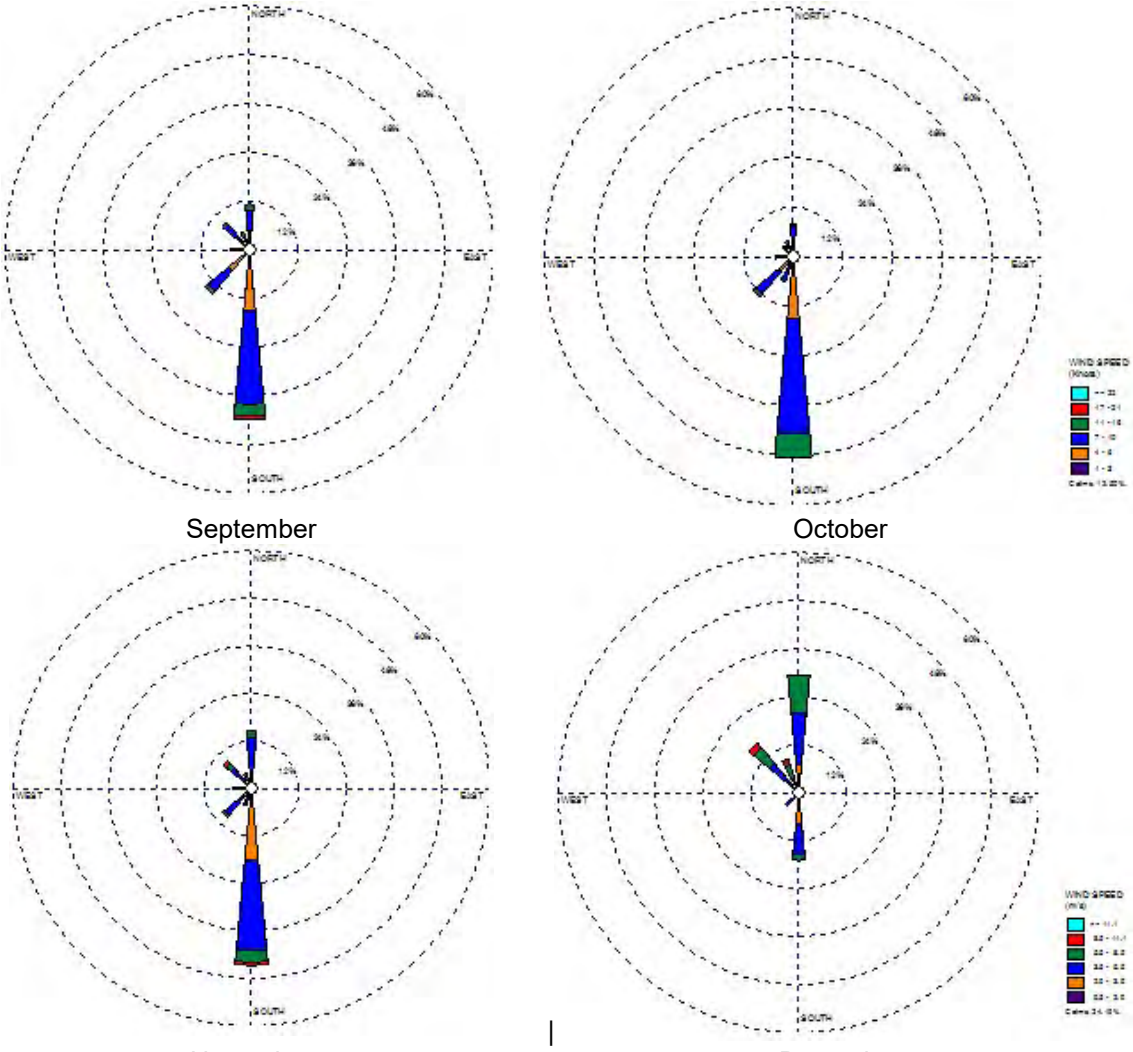
June



July



August



September October

November December

Figure No. 5.273 Annual wind cycle at the Turbo station.

Source: Aqua&Terra Consultores Asociados S.A.S, 2015

From the previous figure it can be seen that for the months of January, February, March and April, the persistent winds are those that come from the north, with magnitudes that can reach 11m / s. In the month of May, a transition of the winds can be seen, becoming the winds that come from the south the most persistent, which extend until November. In December the north winds are again more persistent in the area.

❖ Swell measurement campaign

Additionally, due to the absence of swell records within the bay, the campaigns carried out between February and March 2010 of the Morph Dynamic Modeling Study of Outflows at the Intra-Annual Scale of the National University were taken as a reference.[298].

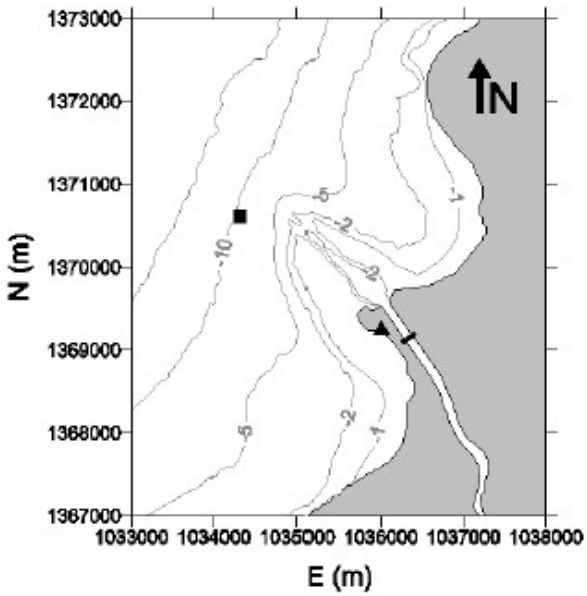


Figure No. 5.274. Location of measuring stations.
Source: Alvarez, 2011. [299]

The measured swell data characterization has been determined by normal distribution, thus obtaining the following values:

Hs average = 0.24 m

Tp average = 4.1 s

[298] Alvarez O., Morph dynamic modeling of outflows at intra-annual scale, National University of Colombia, Headquarters Medellin, 2011.

[299] Alvarez O., Morphodynamic modeling of outflows at intra-annual scale, National University of Colombia, Headquarters Medellin, 2011.

σ Hs = 0.20 m

σ Tp = 0.5 s

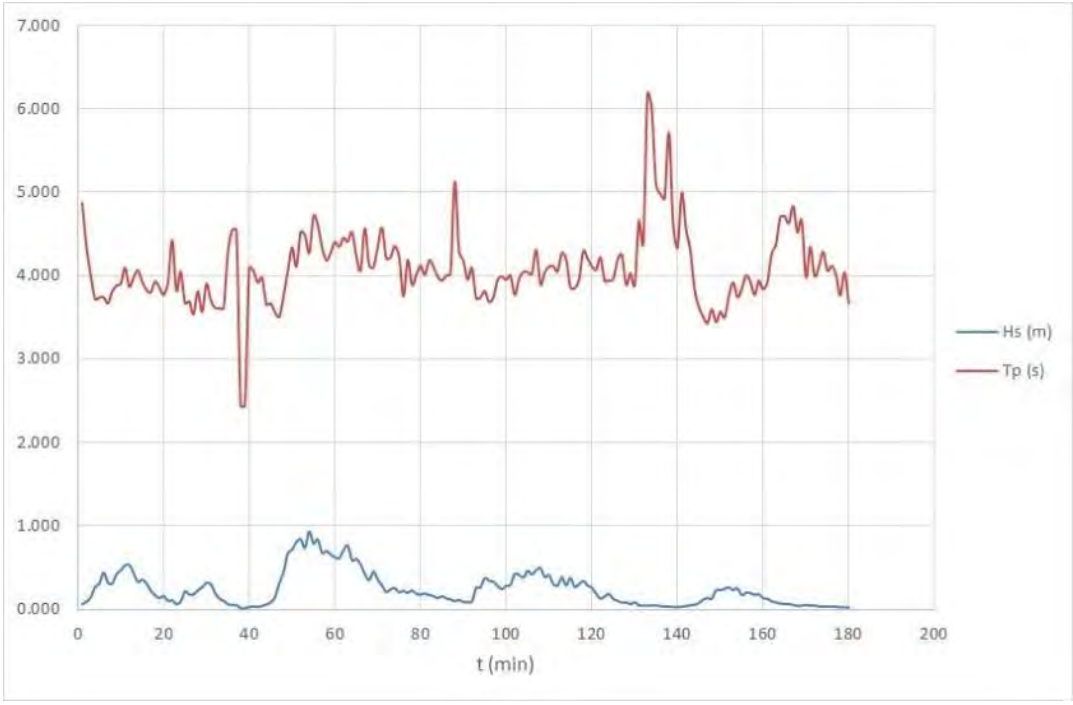


Figure No. 5.275. Swell measurement campaign- February and March 2010.
Source: Prepared by Aqua and Terra Consultores Asociados and data taken from Alvarez, 2011. [300]

❖ Swell propagation

The swell propagation was carried out in order to obtain a characterization of the swell (significant height and direction), along the study area and in greater detail in the vicinity of the proposed landfill, so as to establish its effect in the littoral dynamics of the study area (see Figure No. 5.137).

The propagation cases allow to obtain a qualitative and quantitative image of the propagation process from indefinite depths to the study area, allowing to detect

[300] Alvarez O., Morphodynamic modeling of outflows at intra-annual scale, National University of Colombia, Medellin Headquarters, 2011.

areas of swell concentration or dispersion, to know the angle of incidence of the waves and its height (magnitude) once it has gone through the different processes that the swell suffers when approaching the coast. This work is divided into four types of propagation, the first and the second, consist of determining the average swell regime, from the background and local swell information, in the study zone without works, with this we establish the conditions existing in the study area and the second is with the same propagation cases, but with the bathymetry modified by the project. This will serve to know the impacts that the landfill has on the littoral dynamic of the study area.

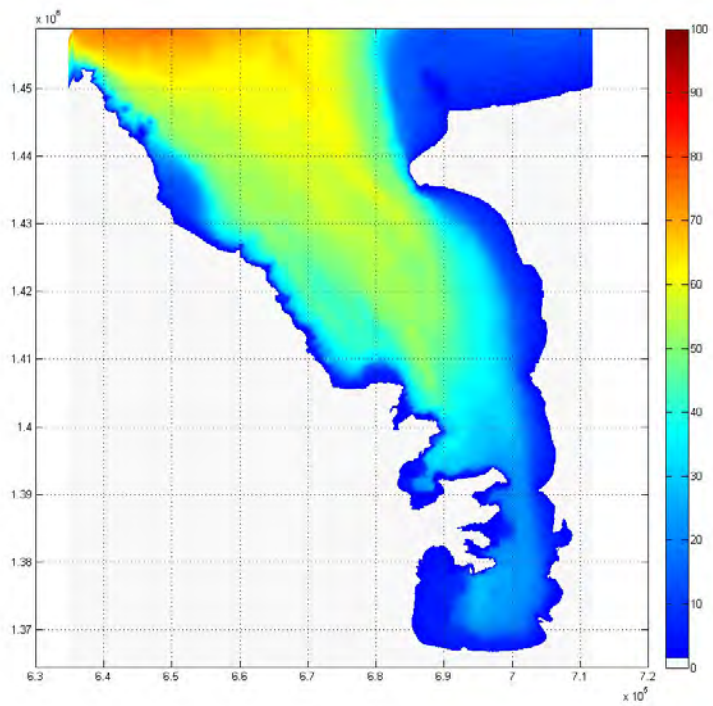


Figure No. 5.276 Study area (taken from the union of nautical charts).
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

This study was carried out with the help of the SWAN model and the Coastal Modeling System of Colombia (SMC-COL), adjusted to the bathymetries of the Colombian coasts by the Oceanographic and Coastal Research Group of the University of Cantabria (GIOC), with the assistance from the General Maritime Directorate (DIMAR). The SMC-COL integrates a series of numerical models, which provide practical support for the correct application of the working methodology for Coastal Engineering.

❖ Description of the propagation numerical model

The SWAN (Simulating WAves Near shore) is a third-generation model, based on the spectral energy of the wave. It was developed as an extension of the third-generation models for deep waters such as WAM and WAVEWATCH, by a team of engineers of the Technological University of Delft. The SWAN is an Eulerian model and is based on the equation of action balance of the wave or energy balance in the absence of currents considering all sources and sinks. The spectrum that is considered in SWAN is the action density spectrum of the N wave (σ, θ) instead of the energy density spectrum E (σ, θ), since in the presence of currents, the density of the action is preserved while the density of the energy is not[301] (WHITHAM, 1974).

- Governing equations

  - The independent variables are the relative frequency σ (as observed in a frame of reference in motion with velocity of the current) and the direction of the wave θ (the normal direction to the peak of the wave of each spectral component). The action density of the wave is equal to the energy density divided by the relative frequency:

$$N(\sigma,\theta) = \frac{E(\sigma,\theta)}{\sigma}$$

Where:

E (σ, θ) = Energy density (Kinetic Energy + Potential Energy per unit area, i.e. the area under the spectral curve

σ = Relative frequency

The equation that governs the SWAN model is the wave action equation of the wave:

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{\text{tot}}}{\sigma}$$

[301] WHITHAM, G. B., 1974: Linear and Nonlinear Waves. John Wiley and Sons, 636 pp.

Where:

N (σ, θ) = Wave action density

C_g = Phase or group speed (Propagation velocity) in space (x, y, σ, θ)

θ = Wave direction

S = Source and energy sinks

The source terms are expressed by:

$$S_{\mathrm{tot}} = S_{\mathrm{in}} + S_{\mathrm{nl3}} + S_{\mathrm{nl4}} + S_{\mathrm{ds,w}} + S_{\mathrm{ds,b}} + S_{\mathrm{ds,br}} \,.$$

Where the terms on the right side of the equation are, the input data: wind, triple wave-wave interactions and inter-quad wave-wave actions, white capping, bottom friction, break by bottom, respectively. Below are some numerical approaches implemented in the SWAN model to solve each of these terms.

- ✓ ***Dissipation by wind (S_{in}):***

$$S_{\mathrm{in}}(\sigma, \theta) = A + BE(\sigma, \theta)$$

Where A describes the linear growth of the wave by the wind and BE describes the exponential growth of the wave by the wind.

- ✓ ***Dissipation by white capping ($S_{ds,w}$):***

White capping formulations are based on the "pulse" model[302], adapted by the group[303]:

[302] Hasselmann, K. (1974). On the spectral dissipation of ocean waves due to white capping. *Boundary-Layer Meteorology*, *6*(1-2), 107-127.
[303] WAMDI group (1988). The WAM model-a third generation ocean wave prediction model. *Journal of Physical Oceanography*, *18*(12), 1775-1810.

$$S_{\mathrm{ds,w}}(\sigma,\theta) = -\Gamma\tilde{\sigma}\frac{k}{\tilde{k}}E(\sigma,\theta)$$

Where Γ is a coefficient that depends on the cant of the wave, k is the wave number, ~k and ~σ are the average wave number and the average relative frequency respectively.

- ✓ ***Bottom Friction dissipation:***

Dissipation by bottom friction can be described by the following expression [304] :

$$S_{\mathrm{ds,b}} = -C_{\mathrm{b}}\frac{\sigma^2}{g^2\sinh^2 kd}E(\sigma,\theta)$$

Where C_b, it is the coefficient of bottom friction.

- ✓ ***Bottom Breakage:***

The model is based on the formulations proposed by (BATTJES AND JANSSEN, 1978) [305], which assume a bore propagation model. This dissipation is described by the following expression:

$$S_{\mathrm{ds,br}}(\sigma,\theta) = \frac{D_{\mathrm{tot}}}{E_{\mathrm{tot}}}E(\sigma,\theta) \qquad D_{\mathrm{tot}} < 0$$

Where D_{tot} is the total energy dissipation rate due to breakage and E_{tot} is the wave's total energy.

[304] Bertotti, L. and Cavaleri, L., 1994, "Accuracy of wind and wave evaluation in coastal regions", Proc. 24th Int. Conf. Coastal Engineering, ASCE, 57-67.

[305] BATTJES, J.A. and Janssen, J.P.F.M., 1978, "Energy loss and set-up due to breaking of random waves", Proc. 16th Int. Conf. Coastal Engineering, ASCE, 569-587

- ✓ ***Dissipation associated with triple and quadruple wave-wave interactions:***

The model to be able to resolve the transfer of energy between wave and wave when the swell is spreading, is based on these formulations to describe this process of energy transfer between wave and wave (resonance phenomenon between waves). So, to solve this process in deep or intermediate waters, it is based on the quadruple wave-wave interaction and for shallow waters the triple wave-wave interaction.

The SWAN model is able to correctly solve the following physical processes related to swell generation and transformation:

- **Dissipation and generation of waves:**
  - White capping
  - Bottom breakage
  - Bottom friction dissipation
  - Wave-wave interaction in deep water and shallow water
  - Generation by wind

- **Propagation:**
  - Propagation through a geographical space
  - Refraction due to spatial variations by the bottom and currents
  - Diffraction (Refraction - Diffraction)
  - Asomeration due to spatial variations at the bottom and currents
  - Blocking and reflection by opposition of the currents
  - Reflection by transmission and blocking over obstacles

- ❖ **Propagated Sea states - medium wave background regime**

In order to obtain the cases to propagate, of the background swell by means of the SWAN model, the propagation case table was constructed, in which the Hs, Tp, θ

variables are considered. For the average regime, the predominant wave directions NNE, N and NNW were chosen, since these are the most representative (80% of the waves come from these two directions), as it was already demonstrated in the previous section. For these directions, a significant wave height was propagated that is only exceeded 12 hours per year (probability of 0.0017% of being exceeded), this in order to know the influence of the landfill on the littoral dynamics, for the most unfavorable conditions of the swell. With respect to the period, a correlation was made Hs vs. Tp with the Barranquilla buoy (nearest buoy) (see Figure No. 5.120) and the characteristic periods for each of the wave heights were determined. Below is the wave rose, the table of directional occurrence probabilities, the Hs vs. Tp correlation and the table with the cases to propagate.

TABLA ESTADISTICOS BASICOS

Variable medida:Hs

direcciones(°)	prob.direccion	$Hs_{12(99.88\%)}$
ESC	--------	3.1732
N	0.0208	3.3916
NNE	0.7697	3.2272
NE	0.1091	1.1131
ENE	0.0000	0.6700
E	0.0000	0.7000
ESE	0.0000	0.4500
SE	0.0001	1.1700
SSE	0.0008	1.1200
S	0.0084	1.3300
SSW	0.0176	1.3191
SW	0.0147	1.2616
WSW	0.0052	1.1900
W	0.0012	1.2500
WNW	0.0031	1.2900
NW	0.0109	2.8964
NNW	0.0275	2.9890

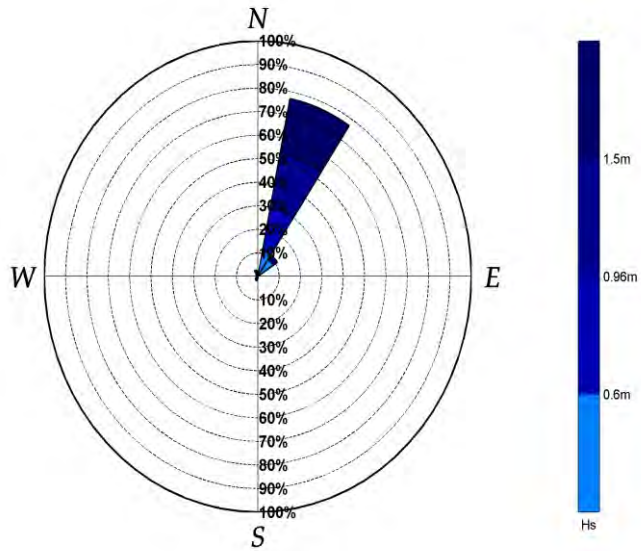


Figure No. 5.277 Mean swell Rose and directional occurrence probability table.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

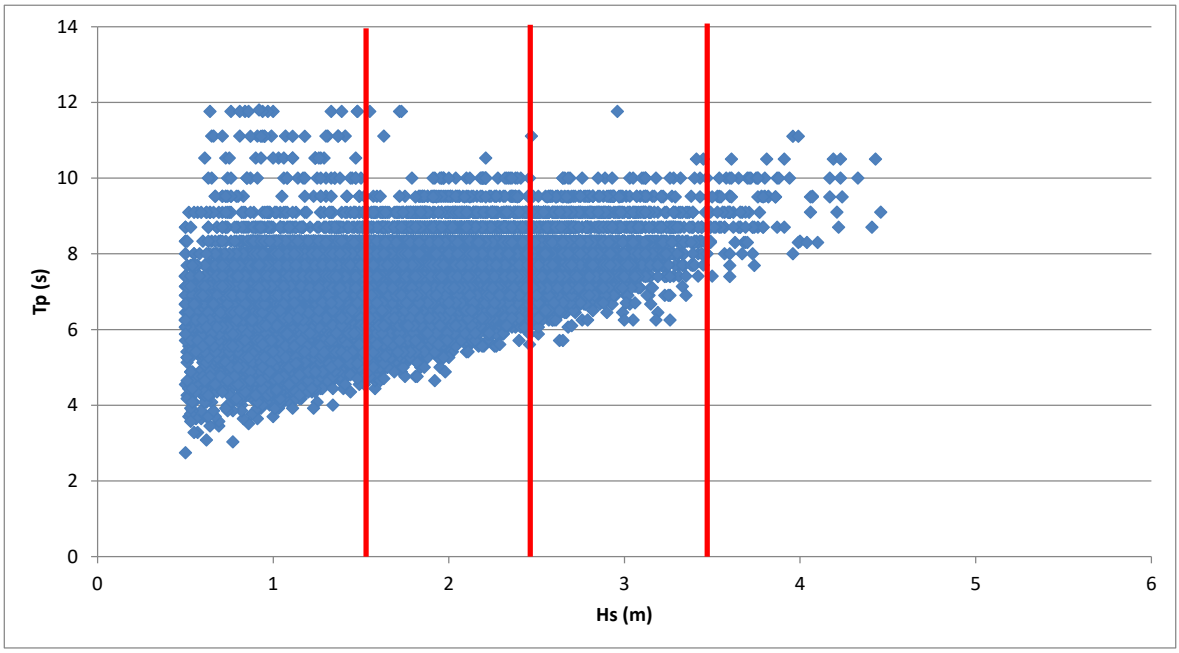


Figure No. 5.278 Hs vs. Tp Correlation for the Barranquilla buoy.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

Table No. 5.109 Cases selected for the construction of the average regime on site.

# Case	Direction	Swell	Hs(m)	Tp(s)	Situation	Situation
1	N	Hs(12)	3.40	9	No Works	With Works
1a	N	Hs(12)	3.40	9	No Works	With Works
2	NNE	Hs(12)	3.25	9	No Works	With Works
2a	NNE	Hs(12)	3.25	9	No Works	With Works
3	NNW	Hs(12)	3.00	9	No Works	With Works
3a	NNW	Hs(12)	3.00	9	No Works	With Works

Source: Aqua&Terra Consultores Asociados S.A.S, 2015

❖ Propagated Sea states- average local swell regime

In order to obtain the cases to propagate, of the local swell (wave produced by the wind inside the gulf) by means of the SWAN model, the propagation case table was constructed, in which the variables of magnitude and direction of the wind are considered. For the average local swell regime, the most representative wind directions were chosen for the study sector, which are N, NNW, NW, SW, S. For

these directions, a wind magnitude of 11 m / s was propagated, this in order to know the influence of the landfill on the coastal dynamics, for the most unfavorable conditions of the local swell. Below is the swell rose, the table of directional occurrence probabilities, the Hs vs. Tp correlation and the table with the cases to propagate.

Below is the table of cases propagated for the local swell, both for the current condition (without landfill) and the future condition (with landfill).

Table No. 5.110 Cases selected for the construction of the average worksite regime.

# Case	Direction	Magnitude (m/s)	Situation
4	N	11.0	Initial
4a	N	11.0	Final
5	NNW	11.0	Initial
5a	NNW	11.0	Final
6	NW	11.0	Initial
6a	NW	11.0	Final
7	SW	11.0	Initial
7a	SW	11.0	Final
8	S	11.0	Initial
8a	S	11.0	Final

Source: Aqua&Terra Consultores Asociados S.A.S, 2015

❖ Bathymetric data

For this study, two bathymetries were carried out: 1) the first bathymetry, takes into account the initial conditions of the study area; for this, the Oceans and Coasts Map Atlas was used, provided by the General Maritime Directorate (DIMAR, 1997) and prepared by the Oceanographic and Hydrographic Research Center (CIOH) (See Figure No. 5.140), the detailed bathymetry of the proposed area for the landfill made by Aqua & Terra Consultores Asociados SAS, in the month of July 2015 (see Figure No. 5.141). The nautical charts that contain the study area are 412 and 625). The second bathymetry, contains the final condition that is expected at the end of the dumping of the material in the proposed landfill sector.

The processing of the bathymetries was carried out with the help of the Coastal Modeling System of Colombia (SMC-COL) and the Matlab software. From the

interpolation of the nautical charts and the detailed bathymetries, a bathymetry was obtained for the study area, with Mercator projection system (WGS 84) (Figure No. 5.142).

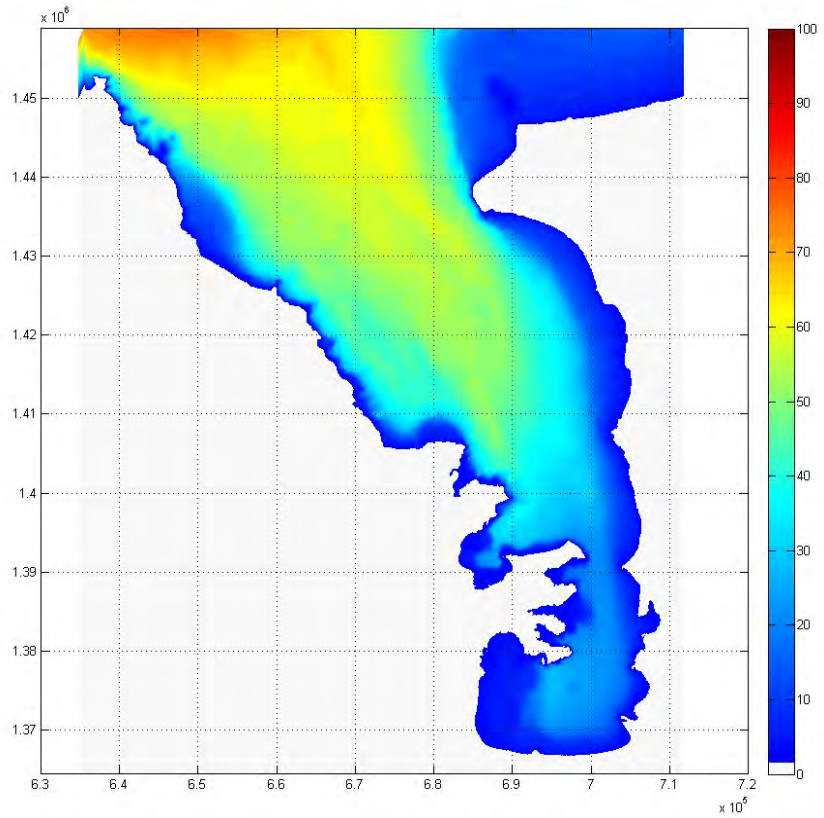


Figure No. 5.279 Base bathymetry, obtained from the nautical charts 412 and 625
Source: Aqua&Terra Consultores Asociados S.A.S, 2015

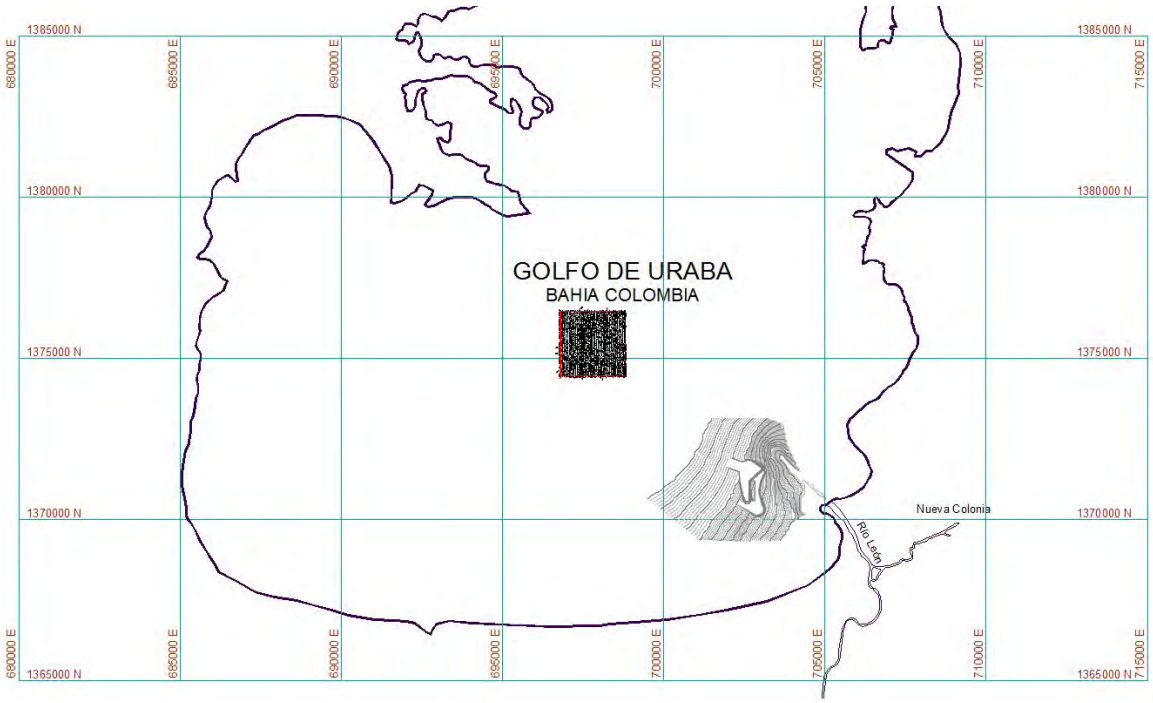


Figure No. 5.280 Detailed bathymetry of the proposed area for the dumping of material from the dredging works of Puerto Bahía Colombia De Urabá and detailed bathymetry of the port area.
Source: Aqua&Terra Consultores Asociados S.A.S, 2015