巻 末 資 料

1. 地下水管理計画（本編のみ、別冊分を除く）

Capacity Enhancement of Groundwater and Seawater Intrusion Management in the Republic of Cuba

Groundwater Management Plan

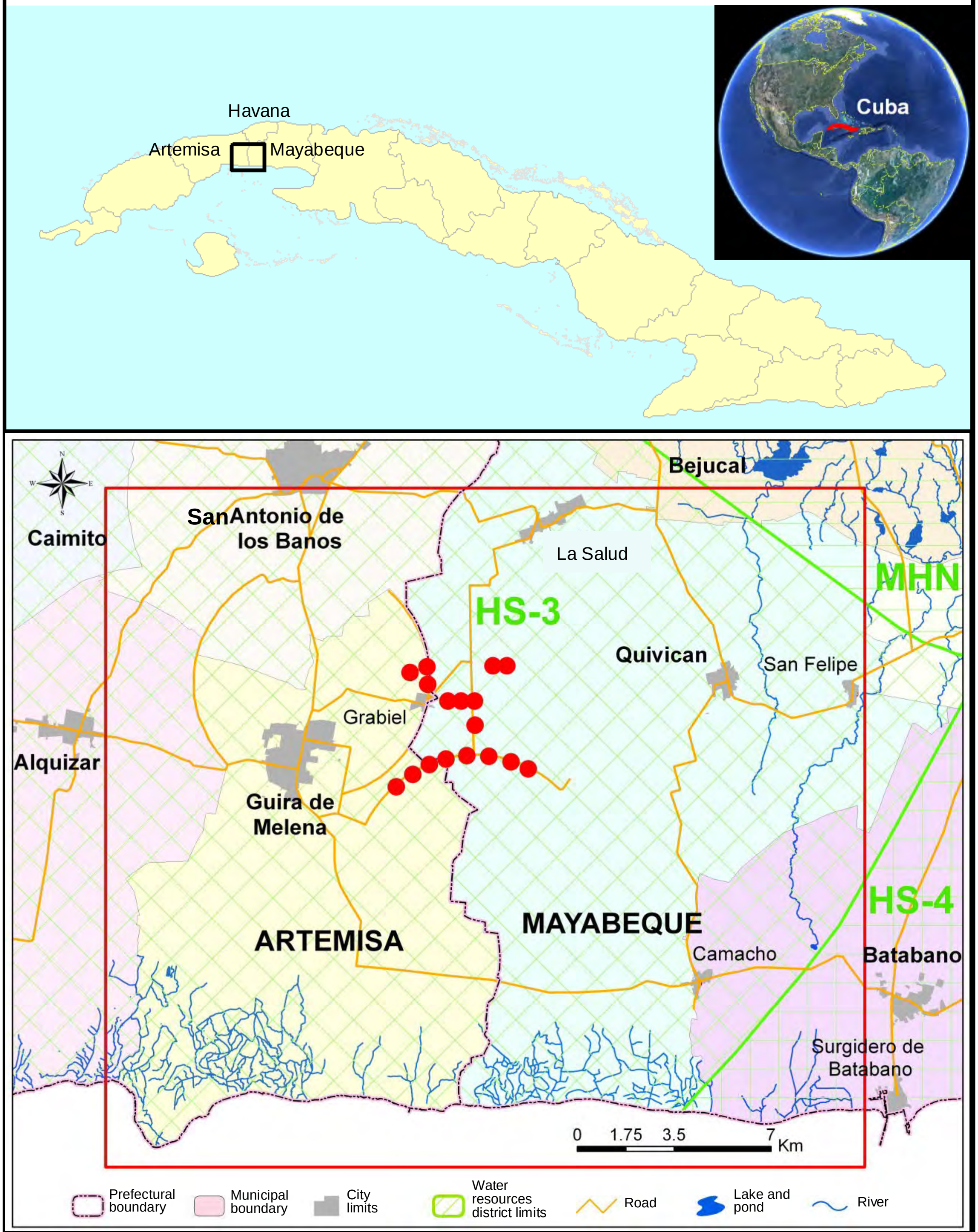
February 2017

Instituto Nacional de Recursos Hidráulicos (INRH)

Y

Agencia de Cooperación Internacional del Japón (JICA)

Republic of Cuba



CAPACITY ENHANCEMENT OF GROUNDWATER AND SEAWATER INTRUSION MANAGEMENT
IN THE REPUBLIC OF CUBA

Location Map of the Target Area

Abbreviations Table

ACC	Academia de Ciencias de Cuba (Cuban Academy of Science)
AMA	Agencia del Medio Ambiente (Environmental Agency)
AZCUBA	Grupo encargado de regular la producción azucarera nacional (The Sugar Group)
BASAL	Bases Ambientales para la Sostenibilidad Alimentaria Local
CAP	Consejo de Administración Provincial (Provincial Administration Council)
CCC (JCC)	Comité de Coordinación Conjunta (Joint Coordination Committee)
CCS	Cooperativa de Crédito y Servicios (Credit and Service Cooperative)
CE (EC)	Conductividad eléctrica (Electrical Conductivity)
CEP (PEC)	Comité de Ejecución del Proyecto (Project Execution Committee)
CGB	Cuerpo de Guardabosques (Forest Rangers Brigade)
CIH	Centro de Investigaciones Hidráulicas (Center for Hydraulic Research)
CITMA	Ministerio de Cienicia, Tecnologia y Medio Ambiente (Ministry of Science, Technology and the Environment)
CPA	Cooperativa de Producción Agropecuaria (Agricultural Production Cooperatives)
CSR (RSC)	Carbonato de Sodio Residual (Residual Sodium Carbonate)
CT	Coliformes Totales (Total Coliform Bacteria)
CTT	Coliformes Termotolerantes (Thermotolerant Coliforms)
CUJAE	Ciudad Universitaria José Antonio Echeverría (*José Antonio Echeverría* University)
DAP	Desarrollo Agropecuario del País (National Farming Development)
DB (BD)	Data Base (Base de Datos)

DBO (BOD)	Demanda Bioquímica de Oxígeno (Biochemical Oxygen Demand)
DQO (COD)	Demanda Química de Oxígeno (Chemical Oxygen Demand)
DPRH	Delegación Provincial de Recursos Hidráulicos (Provincial Delegation of the Water Resources Institute)
EAH	Empresa de Aprovechamiento Hidráulico (Water Management Enterprise)
EIPH	Empresa de Investigaciones y Proyectos Hidráulicos (Hydraulic Projects and Research Enterprise)
EIPI	Empresa de Investigaciones, Proyectos e Ingeniería (Research, Projects and Engineering Enterprise)
EMED	Empresa Ejecutora de Donativos (Donation Execution Enterprise)
ENAST	Empresa Nacional Análisis y Servicios Técnicos (National Analysis and Technical Services Enterprise)
ENPA	Empresa Nacional de Proyectos Agropecuarios (National Farming Projects Enterprise)
ENPC	Empresa Nacional de Perforación y Construcciones (National Drilling and Construction Works Enterprise)
Ep	Porosidad Efectiva (Effective Porosity)
ESIHO	Empresa de Servicios de Ingeniería Hidráulica de Occidente (Enterprise of Hydraulic Engineering Services of the Western Provinces)
GCBAS	Gráfico de Control de Balance de las Aguas Subterráneas (Groundwater Balance Control Graph)
GEAAL	Grupo Empresarial de Acueducto y Alcantarillado (Business Group of the Aqueduct and Sewer System)
GEARH	Grupo Empresarial de Aprovechamiento de Recursos Hidráulicos (Business Group of Water Resources Management)
GEILH	Grupo Empresarial de Ingeniería y Logística Hidráulica (Business Group of Hydraulic Logistics and Engineering)
GEIPI	Grupo Empresarial de Investigaciones, Proyectos e Ingeniería (Business Group of Research, Projects and Engineering)
GPS	Sistema de Posicionamiento Global (Global Positioning System)
Hm3	Hectóic cúblcos (Cubic hectometer)

IAGRIC	Instituto de Investigaciones de Ingeniería Agrícola (Agricultural Engineering Research Institute)
IMTA	Instituto Mexicano de Tecnologías del Agua (Mexican Institute of Water-Related Technologies)
INDER	Instituto Nacional de Deportes, Educacíon Física y Recreación (National Institute of Sports, Physical Education and Recreation)
INRH	Instituto Nacional de Recursos Hidráulicos (National Water Resources Institute)
INSMET	Instituto de Meteorología (Institute of Meteorology)
IPF	Instituto de Planificación Física (Physical Planning Institute)
IPUEC	Institutos Preuniversitarios en el Campo (Rural Pre-university Instituto)
ISO	Organización Internacional de Normalización (International Standards Organization)
ISPJAE	Instituto Superior Politecnico Jose Antonio Echeverría (*José Antonio Echeverría* Higher Polytechnic Institute)
JICA	Agencia de Cooperación Internacional del Japón (Japan International Cooperation Agency)
mbnm (mbmsl)	Metros bajo el nivel del mar (meters below mean sea level)
MEF (FEM)	Método de elemento finito (Finite Element Method)
MES	Ministerio de Educación Superior (Ministry of Higher Education)
MFP	Ministerio de Finanzas y Precios (Ministry of Finance and Prices)
MICONS	Ministerio de la Construcción (Ministry of Construction)
MINAGRI	Ministerio de la Agricultura (Ministry of Agriculture)
MINAL	Ministerio de la Industria Alimentaria (Ministry of the Food Industry)
MINBAS	Ministerio de la Industria Básica (Ministry of Basic Industry)
MINCEX	Ministerio de Comercio Exterior e Inversión Extranjera (Ministry of Foreign Trade and Investment)

MINCIN	Ministerio del Comercio Interior (Ministry of Domestic Trade)
MINED	Ministerio de Educación (Ministry of Education)
MINEM	Ministerio de Energía y Minas (Ministry of Energy and Mining)
MINFAR	Ministerio de las Fuerzas Armadas Revolucionarias (Ministry of the Armed Revolutionary Forces)
MINIL	Ministerio de la Industria Ligera (Ministry of the Light Industry)
MININT	Ministerio del Interior (Ministry of the Interior)
MINSAP	Ministerio de Salud Pública (Ministry of Public Health)
MINTUR	Ministerio del Turismo (Ministry of Tourism)
MIP	Ministerio de la Industria Pesquera (Ministry of the Fishing Industry)
msnm (mamsl)	Metros sobre el nivel del mar (meters above mean sea level)
NMP (MPN)	Número Más Probable (Most Probable Number)
OACE	Organismos de la Administración Central del Estado (Central Government Agencies)
OD (DO)	Oxígeno Disuelto (Dissolved Oxygen)
OIEA (IAEA)	Organización Internacional de Energía Atómica (International Atomic Energy Agency)
OJT	Capacitación en el empleo (On-the-job Trainig)
OLPP	Órganos Locales del Poder Popular (Local Organs of People’s Power)
OMS (WHO)	Organización Mundial de la Salud (World Health Organization)
ONEI	Oficina Nacional de Estadísticas e Información (National Information and Statistics Office)
ONG (NGO)	Organizaciones no gubernamentales (Non Governmental Organizations)

ONN	Oficina Nacional de Normalización (National Standardization Office)
OPS	Organización Panamerican de la Salud (Pan-American Health Organization)
PAURA	Programa de Ahorro y Uso Racional del Agua (Program for the Saving and Rational Use of Water)
PDM	Matriz de Diseño del Proyecto (Project Design Matrix)
PNUD (UNDP)	Programa de las Naciones Unidas para el Desarrollo (United Nations Development Programme)
PO	Plan de Operaciones (Plan of Operations)
RAS	Relación de Absorción de Sodio (Sodium Absorption Ratio)
R/D	Registro de Discusiones (Record of Discussions)
REEANE	Registro Estatal de Entidades Agropecuarias No Estatales (State Register of Non-State-Owned Agricultural Entities)
REEUP	Registro Estatal de Empresas y Unidades Presupuestadas (State Register of Companies and Budgeted Units)
REUCO	Registro Estatal de Unidades Básicas de Producción Cooperativa (State Register of Basic Units of Cooperative Production)
SEF	Servicio Estatal Forestal (State Forest Service)
SIG (GIS)	Sistema de Información Geográfica (Geographic Information System)
SMW	Muro de mezcla de suelo (Soil Mixing Wall)
SP	Potencial Espontáneo (Spontaneous Potential)
Ss	Almacenamiento Específico (Specific Storage)
SST (TDS)	Sólidos Solubles Totales (Total Dissolved Solids)
Sy	Rendimiento Específico (Specific Yield)
TOT	Capacitación de Instructores (Training of Trainers)

UBPC	Unidad Básica de Producción Cooperativa (Basic Unit of Cooperative Production)
UEB	Unidad Empresarial de Base (Basic Business Unit)
UNAICC	Unión Nacional de Arquitectos e Ingenieros de la Construcción de Cuba (National Union of Architects and Construction Engineers)
URA	Dirección de Uso Racional del Agua (Rational Water Use Division)
V2D	Vertical 2 (two) Dimensional

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Appendix (Described in Spanish)

Supplemental report (Described in Spanish)

1 BASIC ELEMENTS OF PLANNING

1.1 Basic Policy

The project is in full correspondence with the National Water Policy approved by the Council of Ministers and in particular under the premises of its four priorities, which are:

1. THE RATIONAL AND PRODUCTIVE USE OF AVAILABLE WATER.
2. THE EFFICIENT USE OF THE INFRASTRUCTURE BUILT.
3. RISK MANAGEMENT ASSOCIATED WITH WATER QUALITY.
4. RISK MANAGEMENT ASSOCIATED WITH EXTREME WEATHER EVENTS.

Therefore, the project is undoubtedly an implementation of the aforementioned priorities to strengthen its results.

a. Short description of groundwater in Cuba

The exploitable mean volume in Cuba, also known as ***Mean Resource*** or ***Annual Ground Mean Runoff***, is estimated at 6457 million m^3/per year, which represents 30% of the total water availability of the country (slightly more than 24 billion m^3/per year). This is distributed in approximately 67% of the territory considered as karstic, characterized by ground basins mostly open to the sea.

This determines the search and use of groundwater, taking into account that there are 165 major basins, and hydrogeological areas with large resources and an effective aquifer area of approximately 37 000 Km2 which is equivalent to 32% of the national territory, so it is estimated that the usable underground volume is more than 50% of the total volume, which reaffirms the importance of groundwater.

The most important aquifers, from the point of view of their storage capacity, are distributed in the west and center areas of the island (Pinar del Río, Havana, Matanzas, Ciego de Avila). Most of these are located and drained to the south coast. In the case of groundwater, the recharge depends mainly on the rain corresponding to the six months of the rainy season.

Out of the 165 *evaluated hydrogeological units* (referred to as basins, spans, and zones), 86 of them store the 77% of the total volume of groundwater. As to the major units freely discharging to the sea at the Gulf of Mexico and the Atlantic Ocean, 16 of them are closed and 70 open, which makes them vulnerable to the problems of seawater intrusion like the rest of the Caribbean islands. There are also about 183 zones, spans, hydrogeological blocks currently evaluated and categorized.

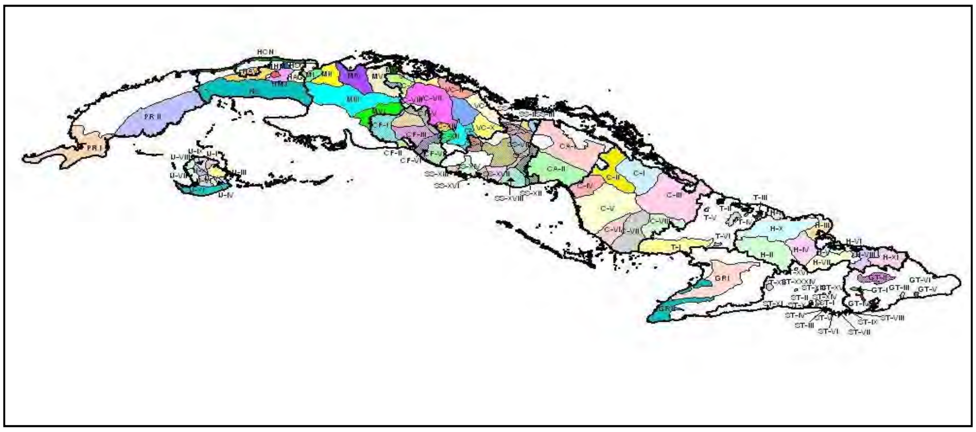

Figure 1-1: Schematic map of underground basins in Cuba

Figure 1-2: Available and potential resources in Cuba

The target area of the project, located in the southern basin of the Artemisa and Mayabeque provinces, has an extension of 690 km^2 in parts of the HS-3 and HS-4 aquifer spans.

In the work area, estimated exploitable resources reach a figure of 482 Hm3 distributed between underground basins HS-3 and HS-4.

Underground runoff basin	Section or sub-basin	Index	Area of Evaluation (Km^2)	Hiperannual Extraction (Hm3 /year)	Exploitation resources (Hm3 /year)
Artemisa Mayabeque	Artemisa – Quivicán Batabanó	HS-3 HS-4	233 180	180 – 280 35 – 55	375 107
Total of basins Σ			413.0		482.0

b. Responsible organization

Instituto Nacional de Recursos Hidráulicos (INRH)

c. Instituciones ejecutoras

GEIPI, GEARH, EIPI-Havana, EAH-Mayabeque, EAH-Artemisa, Water Resource Divisions from Artemisa and Mayabeque Governments, and JICA Study Team

Collaboration system among participating organizations

This project has been carried out taking into account the experience gained during the previous project carried out by JICA in Cuba, named *"Capacity Development on Groundwater Development and Management for Climate Change Adaptation"*.

The program of activities of the Project has been conceived with the integrated participation of the executing organizations, which have guaranteed their corresponding tasks. A timely coordination and flow of information submitted by each participating entity have been achieved.

GEIPI and EIPH-Havana will be the main responsible for hydrogeological studies, groundwater recharge and seawater intrusion.

GEARH, EAH-Mayabeque and EAH-Artemisa will be responsible for the monitoring and groundwater management.

GIS and Groundwater Models will be implemented, developed and used by all the institutions involved in the project.

1.2 Purpose of Planning

a. Background to the preparation of the groundwater management plan (current problems)

Problems currently stated for the groundwater management in the target area include the probable seawater intrusion and groundwater pollution by other factors due to mismanagement and abuse of the use of chemicals. The objective of the Project is mainly to guarantee an available resource to be used if needed and to make up for the deficits in the water supply to Havana. Therefore, this work that is currently carried out in the southern area of the two provinces involved, Mayabeque and Artemisa, encompasses the creation of a groundwater management plan and an adequate and precise use of it.

In the framework of the Project, 7 level sensors have been installed and a bimonthly sampling of the water quality in the target areas is carried out, as well as a monthly sampling of the groundwater levels of the selected exploration networks. At the same time, the MONITORING NETWORK has been satisfactorily restored. This is a necessary and essential tool for an adequate management, maintaining a strict control of the delivery to the users, among which are the main consumers the agricultural activity with the different irrigation systems, aqueducts with the supply to the population, among others.

As to the Management Plan, once it has been technically and administratively approved, we recommend:

- Implement the Management Plan in a sustainable manner.
- Create the Water Use Balance based on this Management Plan.
- Train the parties involved in its implementation.
- Set the control and audit mechanisms for its compliance in a sustainable manner.
- Monitor its implementation to evaluate and propose improvements if necessary.

b. National summary of hydrogeological networks at the end of 2016

As to the condition of hydrogeological networks at the end of 2016, according to the design, the Hydrogeological Network in Cuba is constituted by 2323 wells. Today, 1977 wells are operating for an 85% of completion. This current network is distributed according to its objectives: 589 wells from the Observation Level Information Network; 1568 wells from the Bianuual Exploration Network; 889 wells from the Physical and Chemical Sampling Network and 332 wells from the Bathymetric (hydrochemical- vertical) Network.

Table 1-1: Summary of hydrogeological networks in Cuba

Province	Types of Hydrogeological Networks					
	Design	Current	Information Network	Biannual Exploration Network	Physical and Chemical Network	Bathymetric Network
Pinar del Río	101	83	11	44	85	28
Havana	28	28	12	25	0	3
Artemisa	134	133	37	37	49	41
Mayabeque	117	117	39	120	12	9
Matanzas	259	256	93	256	64	64
Villa Clara	186	170	23	170	53	6
Cienfuegos	182	149	24	149	149	12
Sancti Spíritus	235	84	38	45	26	19
Ciego de Ávila	222	190	52	138	59	34
Camagüey	141	142	20	142	101	41
Las Tunas	155	146	96	96	55	30
Holguín	208	151	46	107	60	13
Granma	142	138	37	90	70	11
Sgto. Cuba	102	93	16	93	6	6
Guantánamo	36	33	22	33	33	3
Isla Juventud	75	64	23	23	67	12
National Total	**2323**	**1977**	**589**	**1568**	**889**	**332**

Map of the project area and its available underground resources.

Since the creation of INRH in August 1962, a true water development policy has been put into practice and the networks of wells and hydrogeological works in general have being intensified.

Due to this, in the early years of the Revolution these networks grew, as a solution to the large number of hydrogeological researches that were carried out and to the need for systematic information regarding every basin of the country.

In the years 1975-78, the project of the national basic network was developed by Bulgarian, Soviet and Cuban specialists. While it is true that it was technically superior, well supported and demanding, in practice showed deficiencies both, in the location of many of the points and in the excessive density of the networks. In the years 1980-81, a first attempt was made to readjust this network, rationalizing many wells and trying to make observations more representatively.

c. Background to the groundwater management plan taking into account its history, meaning, etc., starting from

The creation of hydrological networks in Cuba is closely related to the country's economic development. The intense agricultural management is linked to the activity of urban aqueducts, sugar cane fields and others of various types.

In Cuba, there was no organized design, or a design destined to the observation of the groundwater regime. There were only isolated groups of wells, most of which belonged to different urban and rural aqueducts, which did not provide an accurate description of the aquifer`s behavior. Moreover, there was no systematic control of their condition and it was not until after the triumph of the Revolution that DAP (Spanish initials for Agricultural and Livestock Development of the Country) was founded in 1961. This organization was in charge of the field management of water resources and allowed to drawn up a coherent policy that integrated in a single observation network the different facilities that measured the water level and its quality in the country.

In the 1970s, the design of hydrogeological networks began at the schematic level, based on scientifically explained criteria and it was concluded in the year 1976. However, it showed a series of drawbacks, as it was incomplete, and it was necessary to make a readjustment from 1987 to 1990 which concluded in the year 2000, operational control network for the condition of aquifers.

In the year 2000, the readjustment of the Basic Network Project began with much more depth and detail than the previous ones. Today, they work to have a representative and efficient network.

The HS-3 and HS-4, are the underground basins involved in the project, which have a total area of about 1246 Km2, covering the HS-3 basin with 968 Km2 and the HS-4 basin with 266 Km2. Their hyper-annual extraction resources range from 180-280 Hm3/year in the HS-3 and form 35-55 Hm3/year in the HS-4 with estimated operating resources of 375 Hm3/year for HS-3 and about 107 Hm3/year for Hs-4 with a total of 482 Hm3/year to be handled.

Systematic control and monitoring systems are applied in all underground basins in Cuba and mainly in the selected provinces on a monthly and half-yearly basis. In case of emergencies, basins are tested every 7 and 15 days. There is also an annual control through the balance of national water. In the case of underground basins, mainly the GCBAS method is used, which is very effective and necessary to give a rapid response to the authorities of the country. As to the control assessment and management, the appropriate mathematical models and established calculation methods are used. Thanks to the help of the JICA projects and their trainings, the MODFLOW model and GIS are used, as well as the ACQUIMP Mathematical Model created by the specialists from the Jose Antonio Echevarria university (CUJAE), which is very helpful as it is a purely Cuban product with a surprising high effectiveness.

1.3 Status of the Plan (in terms of Laws and Regulations)

a. INRH's institutional communication strategy

Release to the internal public of INRH and to the society (external public), through the mass media, every organization`s achievement of public interest, emphasizing the central role played by the workers and leaders of the National Institute of Water Resources.

Contribute to the support of a general and comprehensive culture around the imperative rational use of water in all of its usages, whether it comes from surface or underground sources, both, in the residential as well as in the state sector, particularly with the growing resonance of the Water Balance as a basic category of the plan of the economy and for the establishment of efficiency rates in the economic and social activities of the country.

Likewise, pass on the awareness regarding the economic value of water and the imperative need to protect it in terms of quantity and quality.

Boost the interpretative flexibility and the proactive nature from the INRH Institutional Level as a contribution to continue stressing the positioning, in the mass media discourse, of the nuances that define the functional and performance differences between the communication parties located in the state field, from those located in the business sector.

DANDO CUMPLIMIENTO A LOS LINEAMIENTOS DE LA POLITICA ECONOMICA Y SOCIAL DEL PARTIDO Y LA REVOLUCION REFERIDO A RECURSOS HIDRAULICOS LOS CUALES SE ENMARCAN ENTRE LOS LINEAMIENSTO 300 AL 303, Y CUMPLIENDO CON LOS INDICATIVOS DEL PROGRAMA, SOBRE EL RESULTADO 4. (ENFORCING THE GUIDELINES OF THE ECONOMIC AND SOCIAL POLICY OF THE PARTY AND THE REVOLUTION RELATED TO WATER RESOURCES WHICH ARE STATED FROM GUIDELINE 300 TO 303, AND IN COMPLIANCE WITH THE INDICATIONS OF THE PROGRAM ON THE RESULT 4.)

IN ORDER TO MEET THE OBJECTIVES OF THE PROJECT, IT IS ESSENTIAL TO TAKE INTO ACCOUNT THE MANUALS AND DIRECTIVES THAT CONTROL THE ECONOMY OF THE COUNTRY, SUCH AS:

- **DECRETO -LEY NUMERO 138** DE LAS AGUAS TERRESTRES (**DECREE-LAW NUMBER 138** ON TERRESTRIAL WATER).
- Metodología apara la elaboración del balance de agua (Methodology to draw up the water balance).
- **Resolución 169/2012**, modelo de reasignación operativa del agua (**Resolution 169/2012**, model for the operational reallocation of water).
- **Resolución 170 balance 4-10-12**; Resolución 45-91 INRH, y Resolución No 21-99 (**Resolution 170 balance 4-10-12**; Resolution 45-91 INRH, and Resolution No. 21-99).
- **Resolución 21/99** del Presidente del Instituto Nacional de Recursos Hidráulicos (INRH) que pone en vigor las normas netas y eficiencia para los sistemas de riego. (**Resolution 21/99** of the President of the National Institute of Water Resources (INRH), putting into effect the clear rules and efficiency standards for irrigation systems).
- **Resolución 45/91** del Presidente del Instituto Nacional de Recursos Hidráulicos (INRH) que pone en vigor los medios de consumo para el sector de la Economía no agrícola. (**Resolution 45/91** of the President of the National Institute of Water Resources (INRH), putting into effect the consumables for the non-agricultural economy sector.).
- **Norma Cubana 53-91/83** para la determinación de la demanda de agua potable. (**Cuban Standard 53-91/83** to determine the drinking water demand.).
- **Resolución 15/98** del Instituto Nacional de Recursos Hidráulicos (INRH) que pone en vigor la metodología para la elaboración del Balance de Agua. (**Resolution 15/98** of the President of the National Institute of Water Resources (INRH), putting into effect the methodology to draw up the Water Balance.).

- Resolución del año correspondiente según Presidente del Instituto Nacional de Recursos Hidráulicos (INRH) que establece el calendario y el cronograma de ejecución del Balance de Agua. (Resolution of the corresponding year according to President of the National Institute of Water Resources (INRH) setting the calendar and the schedule for the carrying out of the Water Balance.).

- **Resolución 58/95** del presidente del INRH que pone en vigor la Resolución 45/91. (**Resolution 58/95** of the President of INRH, putting into effect Resolution 45/91.).

- **Resolución 95/2005** del presidente del INRH para los embalses destinados al abasto a la población y los de uso compartido. (**Resolution 95/2005** of the President of INRH for reservoirs assigned to supply water to the population and those of shared use.).

- **Resolución 24/99** del presidente del INRH que establece los Gastos Sanitarios. (**Resolution 24/99** of the President of INRH, setting out Health Expenses.).

- **Decreto Ley 199/99** Sobre la seguridad y protección de la información. (Decree-Law 199/99 on the security and protection of information.).

b. Legal framework on water in Cuba

The use of water, its conservation, care, study and prospecting are regulated by laws, decrees and resolutions. The Cuban State has delegated the responsibility of the Comprehensive Water Management to the National Institute of Water Resources, created on August 10, 1962.

Cuba was ruled by the Royal Decree of January 9, 1891, that validated the Water Law of June 13, 1879, putting in force the Regulation of the Water Law and other presidential orders and decrees that had become obsolete for the social and economic conditions of the date, until June 1, 1993, when Decree-Law 138 on Terrestrial Water came into force.

The regulating documents include those aimed at regulating major activities, such as violation, state inspection, hydrographic basin protection, rational use of water resources, rights of use, water quality, the operations of reservoirs, etc.

c. Procedures

At the beginning of the process to draw up the Water Balance, the availability of water from the supply sources is assessed and user organizations are informed of possible difficulties as to guaranteeing the water for the year that is planned.

Based on delivered water availabilities, the maximum water intake quotas and the water needs of the production or service plans, user organizations present the water demands to the Water Management Enterprises in their territory, including the expected level of activity and water intake standards according to the officially approved documents:

- **Resolución 21/99** del Presidente del INRH, que pone en vigor las normas netas y eficiencias para el riego. (**Resolution 21/99** of the President of INRH, putting into effect the clear rules and efficiency standards for irrigation systems.).

- **Resolución 45/91** del Presidente del INRH, que pone en vigencia las índices de consumo para el sector de la economía no agrícola. (**Resolution 45/91** of the President of INRH, putting into force the intake rates for the non-agricultural economy sector.).

- **Norma Cubana 53 - 91/83** para la determinación de la demanda de agua potable. (**Cuban Standard 53 - 91/83** to determine the drinking water demand.).

Based on the water demands received from the user entities, Water Management Enterprises will prepare the balances of the supply sources, taking into account the technical criteria stated.

In addition to the set tables, the balance report will also include an analysis of the results of the report, both, from the point of view of the most significant aspects to be taken into account in the exploitation of the sources, and from an analysis of the needs met for the main users.

Once the Water Balance proposal is prepared on each territory and discussed by the Water Resource Delegations, it is submitted to the Government of the province.

The final document will be discussed with the RATIONAL WATER USE DIVISION and the Water Resource Delegates will make the final presentation to the President of INRH.

1. **Decreto - Ley No 138.** De las aguas terrestres. 1ro de junio de 1993. (**Decree-Law No. 138.** On terrestrial water. June 1, 1993.).
2. **Decreto - Ley No 199.** Contravenciones de las regulaciones para la protección y el uso racional de los recursos hidráulicos. (**Decree-Law No. 199.** Violations to the regulations for the protection and rational use of water resources.).
3. **Decreto - Ley No 211.** Contravenciones de las regulaciones para los servicios de acueducto y alcantarillado. (**Decree-Law No. 211.** Violations to the regulations for aqueduct and sewer system services.).
4. **Resolución No 6/96 del INRH.** Reglas para el cobro del derecho de uso y el servicio de provisión de aguas terrestres. (**Resolution 6/96 of INRH.** Rules to collect the right of use and the terrestrial water provision services.).
5. **Resolución No 12 del INRH.** Autorización de utilización de aguas embalsadas en presas en explotación o en proyecto. (**Resolution No. 12 of INRH.** Authorization to use the water collected in operating dams or in the project.).
6. **Resolución No 18 del INRH.** Regulación del procedimiento para la solicitud de aprobación de extracción total o parcial del agua de un embalse para la captura de especies existentes. (**Resolution No. 18 of INRH.** Regulation of the procedure to request approval for the total or partial extraction of water from a reservoir for the capture of existing species.).
7. **Resolución No 25 del INRH.** Reglamento de la inspección estatal de recursos hidráulicos. (**Resolution No. 25 of INRH.** Regulations on the water resource state inspection.).
8. **Resolución No 20 del INRH.** Definición de características técnicas de las obras hidráulicas. (**Resolution No. 20 of INRH.** Definition of the technical characteristics of water works.).
9. **Resolución No 30 del INRH.** Proposición de disminución de niveles de agua de embalses. (**Resolution No. 30 of INRH.** Proposition for a downward of the water levels in reservoirs.).

10. **Resolución No 55.** Regulación de ejecución de perforaciones. (**Resolution No. 55.** Regulation of the carrying out of drilling.).

11. **Resolución No 56.** Sobre el papel inversionista del INRH. (**Resolution No. 56.** On the INRH's role as investor.).

12. **Resolución No 114.** Sobre las entidades facultadas para realizar proyectos de obras hidráulicas. **- INRH - MIP.** Reglamento sanitario para la explotación comercial en embalses utilizados como fuente de abastecimiento de agua a la población. (**Resolution No. 114.** On the entities authorized to carry out water projects. **- INRH – Ministry of the Fishing Industry.** Health regulations on the commercial exploitation in reservoirs used as a source of water supply to the population.).

13. **Resolución No 24/99 del INRH.** Caudales ecológicos de las presas. (**Resolution 24/99 of INRH.** Ecologic volumes on dams.).

14. **Resolución P – 6 del MFP 2000.** Tarifas para el cobro del servicio de provisión de agua y del derecho de uso. (**Resolution P – 6 from the Ministry of Finance and Prices 2000.** Fees for the collection of the water supply service and the right of use.).

The Water Balance as the relationship between the water demand and the availability is drawn up in the provincial EAHs and DPRHs based on the demands submitted by the users of the territory and the organizations, and it is discussed and set at the National Institute of Water Resources. The process concludes with its agreement in the economy plan approved by the Council of Ministers as another directive indicator of the economy plan.

Evaluations are carried out on an annual basis in order to assess the water for the different economic and social activities according to the availability of the supply sources for the year that is planned.

For the specific conditions of drought periods a thorough work is required that allows to begin a recovery process to stabilize the delivery of supply sources with a more rational distribution of water and the minimum affectations possible.

d. THE WATER BALANCE is part of the economy of the country under a more efficient control

It is subjected to the following premises:

- Schedule and procedure. **Yearly Ministerial Resolution.**
- Balance methodology. **Resolution 15/98**.
- Irrigation standards and efficiency of the techniques used. **Resolution 21/99.**
- Drinking water demand in populations. **Cuban standard.**

Water System

Water System refers to the set of sources and works having a water link where users can indistinctly receive supplies from one source or another.

Source

It is the reservoir, river, pond or underground basin where a water supply originates. When several sources make up a water system, the entire system is considered to be a source.

Isolated Source

Is the one with independent operation for the exploitation, i.e. is not part of a Water System.

Compensation Regime

It is set between a regulated source and an unregulated river, where the river deficit is compensated with water volumes delivered by the regulated source.

Common Link

It is set when the user benefits from the compensation in a system or when it can get supplies from several sources that work jointly.

Direct Link

It is set in a water system where certain users can only get supplies directly from a specific source of the system. In the case of isolated sources there is always a direct source-user linkage.

d.1 Duties of GEARH

It ensures that the water supply service is carried out under the premise of delivering the agreed volume of water, with the necessary flow, to the agreed place, at the set time and with the required quality, through a hydraulic infrastructure with technical conditions of excellence, with the integration of provincial EAHs, through the following:

1. Controls, advises and evaluates the preparation of the Annual Water Balance.
2. Controls the execution and compliance of the Annual Water Balance.
3. Supervises and insists on the efficient use of water resources, based on the priorities set.
4. Controls and insists on the proper exploitation of works, and the proper operation of the Systems and Networks.
5. Advises and/or participates in the organization and control of the source exploitation, linked to the supply to the population, rice production, tourism, livestock, power generation, agriculture and others; in order to prevent or avoid irreversible damages to the Society and the Economy.
6. Supervises labor relations, along with the Civil Defense, the Meteorology Institute, the Ministry of Science, Technology and the Environment (CITMA) and others, to plan joint actions that contribute to the rational and logical solution of adverse climate events and water pollution.
7. Complies and demands compliance with the legal bases in force related to the administration, management, protection and efficient use of water resources.
8. Analyzes and recommends the evaluation and use of new technologies in its field of expertise (Water Management and Observation Networks for the water cycle variables).
9. Recommends, advises and participates in developing trainings for specialists and techniques for the activity.
10. Advises and participates in the carrying out of works and systems under exceptional conditions.

d.2 Water management process and networks

1. To issue the indications to draw up the Annual Water Balance, complying with the guidelines of the National Institute of Water Resources.
2. To control the correct drawing up of the Water Balance in the fifteen provinces.
3. To perform a quarterly control of the implementation of the Water Balance.
4. To guarantee an adequate operation of the observation networks of the water cycle, carrying out a systematic control.
5. To perform an effective control of the Exploitation Hydrometric Works that allows the correct operation of the systems and the efficient use of the water resources.

Table 1-2: GEARH's documents to control processes

CODE	TYPE OF DOCUMENT	DESIGNATION OF DOCUMENT O
R-05-01	Record	Summary of the Water Uses.
R-05-02	Record	Decennial Report on the Behavior of Surface Sources according to their Annual Delivery Plan.
R-05-03	Record	Groundwater Use in the Category I Basins.
R-05-04	Record	Groundwater Use...
R-05-05	Record	Rain Behavior.
R-05-06	Record	Surface Water Use.
R-05-07	Record	Condition of the Reservoirs.
R-05-08	Record	Conclusions Report of the Visit to Inspect the Water Management Activity and Networks.
R-05-09	Record	Summary of the Exploitation Project Revision.
R-05-11	Record	Quarterly Report of Physical Indicators.
R-05-12	Record	Quarterly Compliance with the Physical Indicators.
R-05-13	Record	Current Status of the Exploitation Hydrometric Works
R-05-14	Record	Inventory of Hydrometric Works for the Exploitation of Water Systems.
FP - 05	Process Index Card	WATER MANAGEMENT AND NETWORKS
PR-05-05	Procedures	Performance in exceptional situations.
PR- 05-06	Procedures	Control of the physical indicators of management efficiency on subordinated organizations.
PR- 05-07	Procedures	Control and inspection of the hydrometric exploitation activity in water systems.
IT- 05-01	Directive	Draw up of the Water Balance.
IT-05-02	Directive	Collection, processing and issuance of the Decennial Information.
IT-05-05	Directive	Collection, processing and issuance of the information to write the

		chapter on the Condition of Underground Basins.
IT-05-07	Directive	Collection, processing and issuance of the information to create the page on the Surface Water Use.
IT-05-08	Directive	Collection, processing and issuance of the information to create the page on the Situation of Reservoirs.

1.4 Target Area of the Plan

The governing Central Administration Bodies in the selected study area are the following:

- Provincial Administration Council (CAP, by its Spanish initials) of Mayabeque, where the Water Resource Division of CAP is located.
- Provincial Administration Council (CAP, by its Spanish initials) of Artemisa, where the Water Resource Division of CAP is located.

The data provided herein has been taken from the Legal Registries of the National Information and Statistics Office (ONEI by its Spanish initials), that is to say, the State Registry of Companies and Budgeted Units (REEUP, by its Spanish initials), the State Registry of Non-State-Owned Agricultural Entities (REEANE, by its Spanish initials), and the State Registry of Basic Units of Cooperative Production (REUCO, by its Spanish initials), in which all agricultural cooperatives are registered (including CPA (Agricultural and Livestock Production Cooperatives), CCS (Credit and Service Cooperatives) and UBPC (Basic Units of Cooperative Production) and the administrative list of the entirely Cuban companies.

- Project executing enterprises

  a. Empresas Aprovechamiento Hidráulicos Provincial Mayabeque. (Provincial Water Management Enterprise of Mayabeque).

  b. Empresas Aprovechamiento Hidráulicos Provincial Artemisa. (Provincial Water Management Enterprise of Artemisa).

1.5 Length of the Plan

The following predictions have been made as to the length of the plan:

- Short-term length: A length of no less than 5 years of exploitation with an efficient groundwater management in the aquifer has been determined.
- Mid-term length: A length of no less than 20 years of exploitation with an efficient groundwater management in the aquifer has been determined, under a strict compliance with the requirements stipulated and specified by the project.
- Long-term length: A length of no less than 30 years of exploitation with an efficient groundwater management in the aquifer has been determined, under a strict compliance with the requirements stipulated and specified by the project.

2 ESTIMATED GROUNDWATER CURRENT CONDITION IN THE TARGET AREA

2.1 Hydrological Description

a. Meteorology

a.1 Climatic characteristics

According to Köppen's classification, the climate is tropical hot, with a rainy season during the summer. The climate of the study area can be described in general as tropical, seasonally humid and with maritime influence.

Due to its geographical position, it is located in latitude very close to the Tropic of Cancer, and this conditions the reception of high values of solar radiation throughout the year, causing the warm nature of its climate. In addition, it is located in the border between the zones of tropical and extratropical circulation, receiving the influence of both of them with a seasonal nature. In the season that runs approximately from November to April, the variations of weather and climate become more noticeable, with abrupt changes in the daily weather, associated with the passing of frontal systems, the anticyclonic influence of continental origin and the extratropical low pressure centers. On the other hand, there are few variations in the weather from May to October, with a relative marked influence of the North Atlantic Anticyclone. Major changes are related to the presence of disturbances in the tropical circulation (eastern waves and tropical hurricanes).

Temperatures are generally high. Annual mean values range from 21°C to 27°C. The records of the average maximum temperature are between 27˚C and 33˚C and the average minimum temperature is between 15˚C and 23˚C. The hot season runs from November to April, while the hottest months are from May to October.

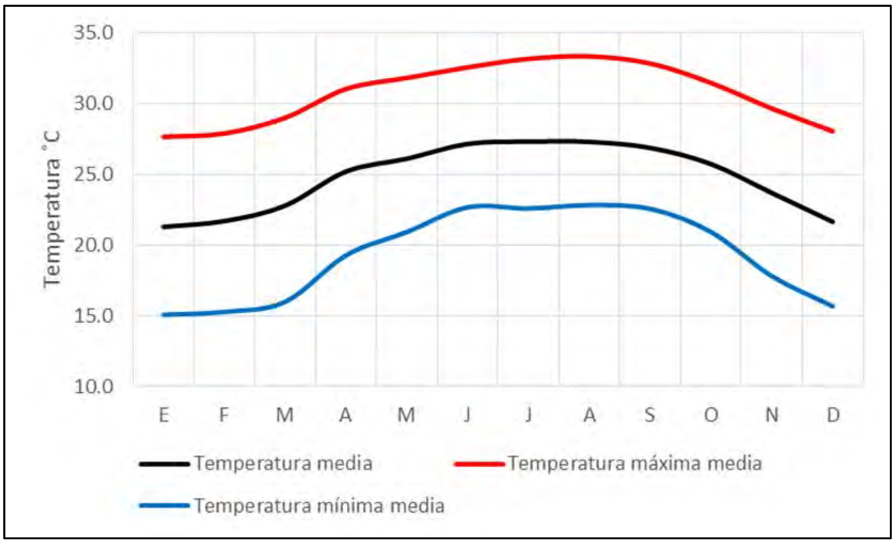

Figure 2-1: Annual temperature behavior at the Batabanó weather station

The average relative humidity is high, with figures close to 80%. The daily maximum value, generally over 90%, occurs at sunrise, while the minimum value falls up to 50 - 60% at noon in the inland.

Winds from the East component prevail in the area. From November to April, courses from the first quadrant are predominant due to the influence of meteorological systems of the winter season; while in the summer, the winds blow more towards the Southeast, especially with the withdrawal of the anticyclonic wedge. Maximum wind velocities occur with the passing of cold fronts, extratropical hurricanes, local storms, hurricanes, among other phenomena. Local wind systems are also of interest, with the presence of a central convective belt and the coastal influence of sea and land breezes, strengthened or weakened depending on the predominant wind flow. The anticyclonic influence is predominant throughout the year, with higher values and higher pressure gradients in the winter months.

Rainfall is the most variable element in the climate of the study area. There are two main seasons: rainy (from May to October), with approximately 80% of the total annual rainfall and of little rain (from November to April). The areas with the highest rainfall, with values above 1 500 mm per year are located to the North of the territory. However, values below 900 mm are reported on the coast.

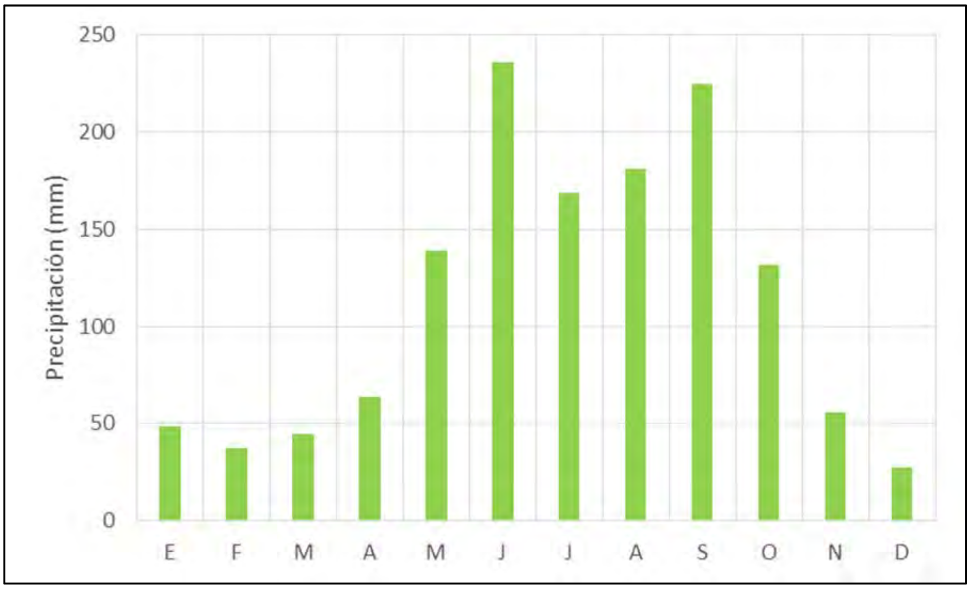

Figure 2-2: Rainfall monthly average 1961-2000 periods

The higher rainfall volumes are associated with some of the most important meteorological phenomena (tropical hurricanes, cold fronts, tropical waves, etc.) or have their origin in the daytime warming. They almost always occur in the afternoon in the form of short-length episodes. Heavy rain periods can occur in the presence of large-scale meteorological systems, particularly in the months from May to June and September-October.

Evaporation values are high, reaching up to 1800 mm per year. The latitude and structure of the slopes, the distance to the coast, the degree of exposure to the wind, among other factors influence its spatial and temporal distribution.

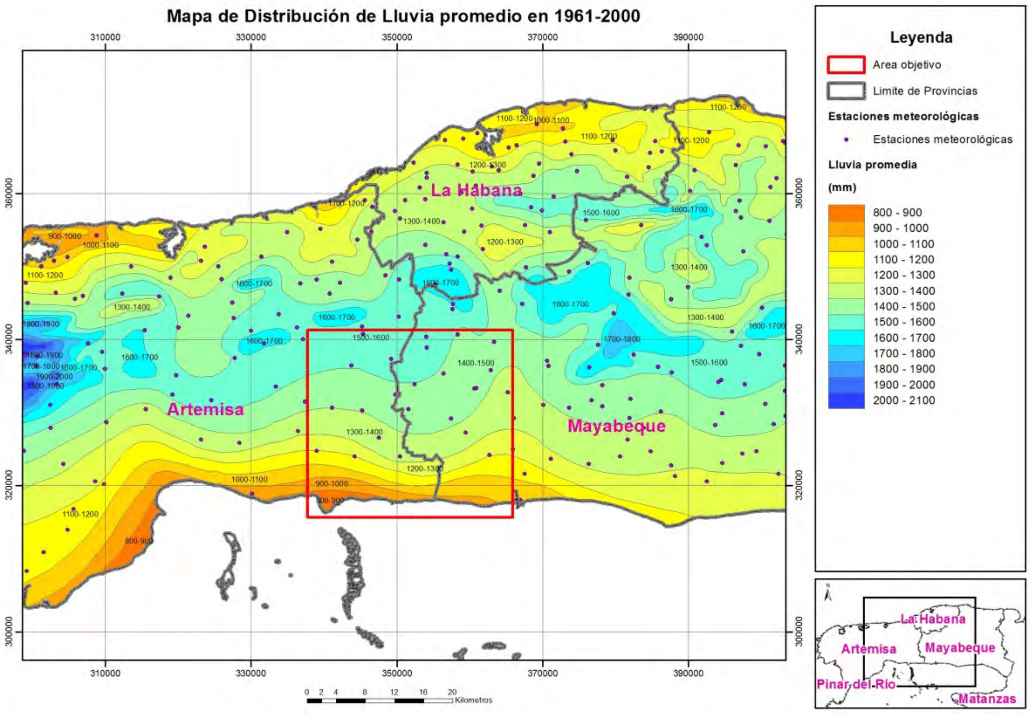

Figure 2-3: 1961-2000 Average rainfall distribution map

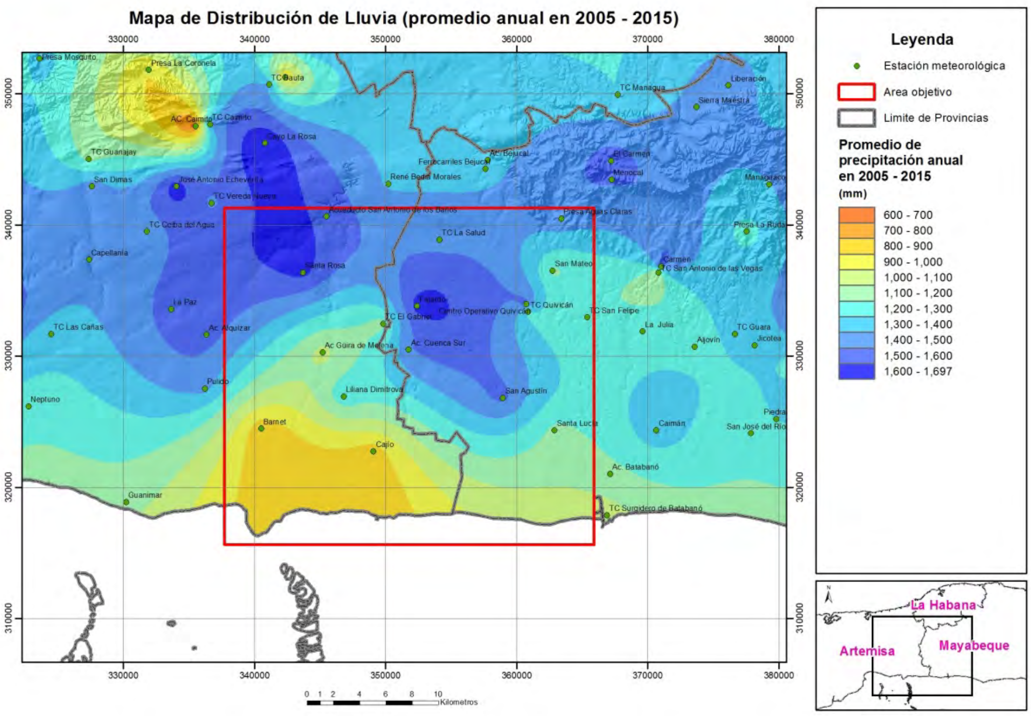

Figure 2-4: 2005-2015 Average rainfall distribution map

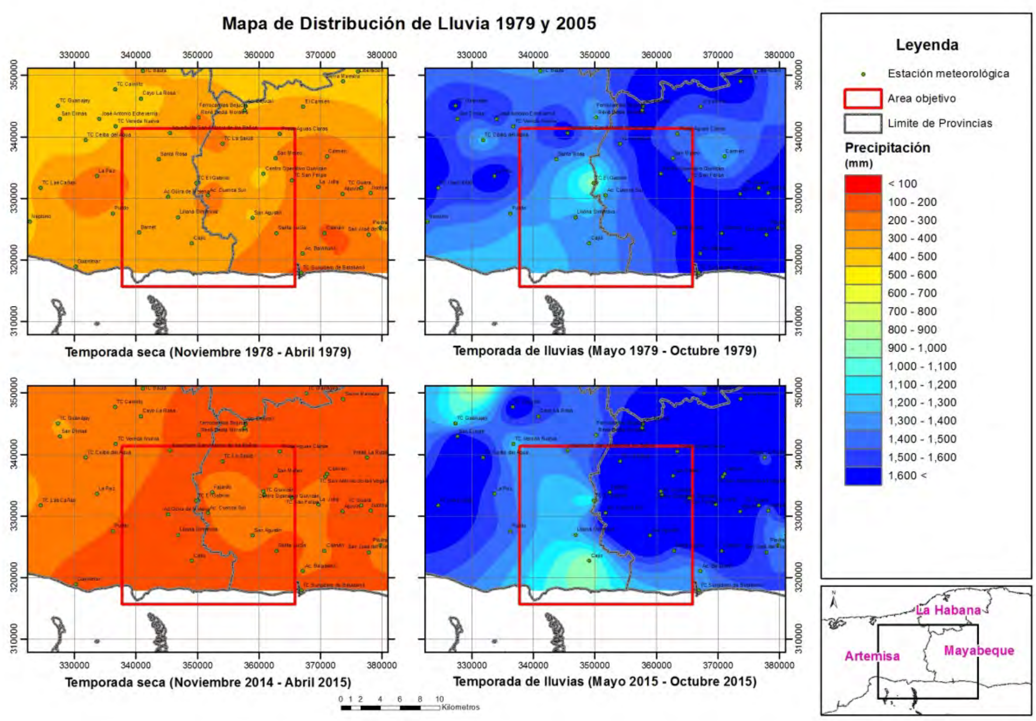

Figure 2-5: 1979 and 2015 Rainfall distribution map

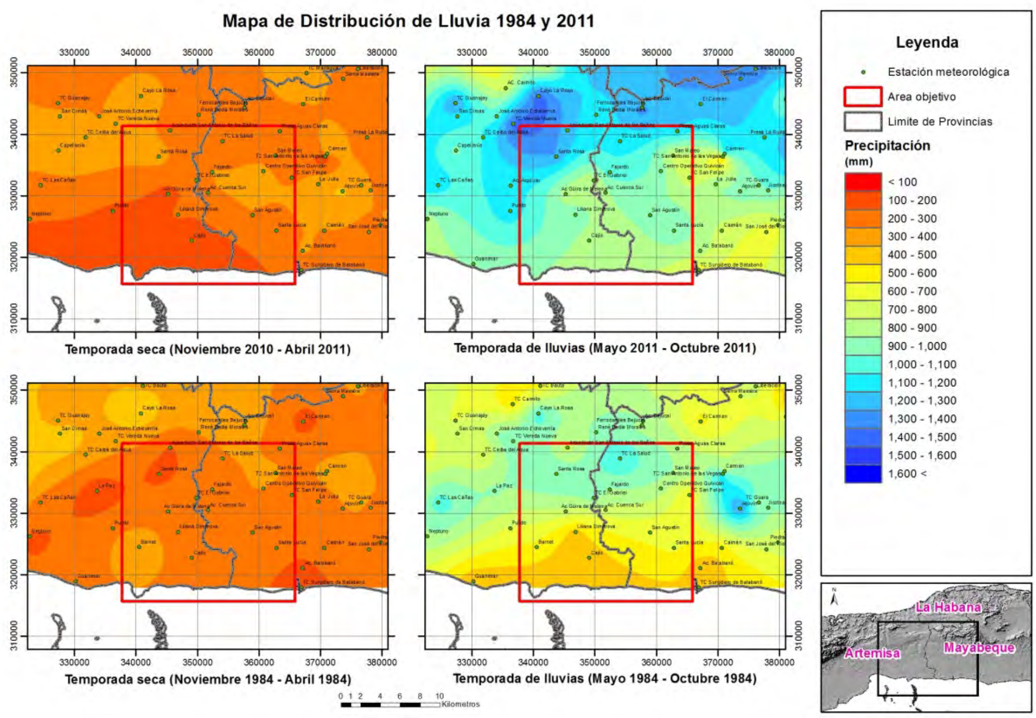

Figure 2-6: 1984 and 2011 Rainfall distribution map

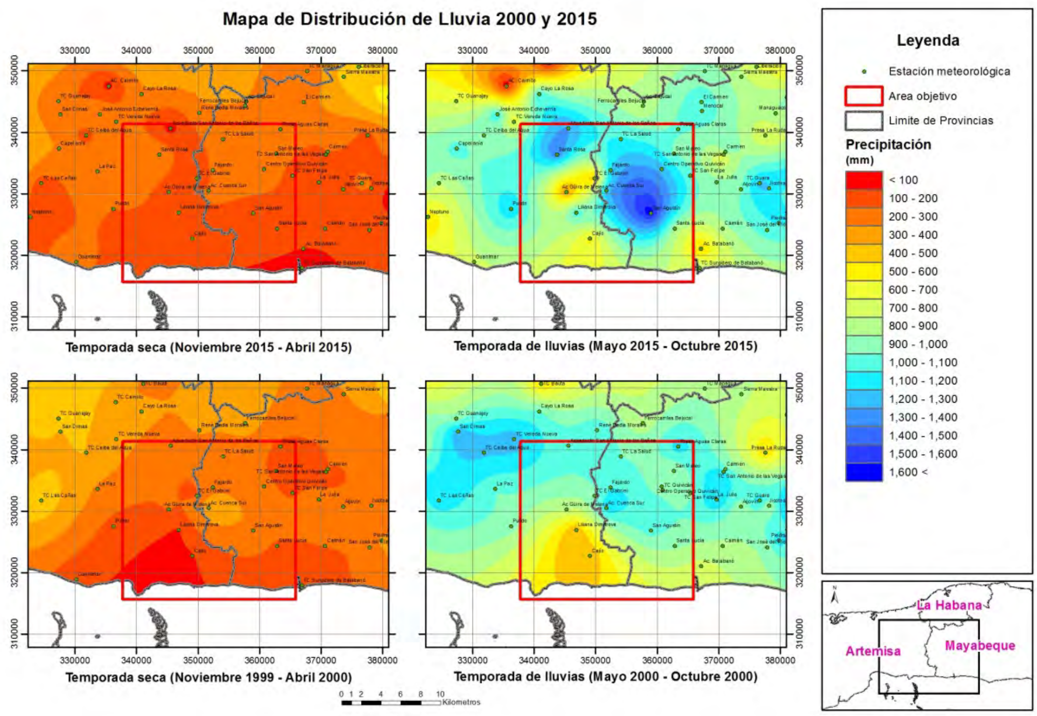

Figure 2-7: 2000 and 2015 Rainfall distribution map

b. Surface water

The surface drainage network in the target area is practically non-existent, given the characteristics of the soil and the substrate. Only one area of the hydrographic basin of the Quivicán River towards the west is defined. This river, like its main affluent, San Felipe river, was born in the heights of the Pre-Neogene age, located to the North of the area. The runoff is regulated by dams and microdams and it has an intermittent nature. Its course is lost into the plain through karstic pipes. The mean annual runoff module in this basin is estimated between 10 l/s*km^2 to the North and 5 l/s*km^2 to the South.

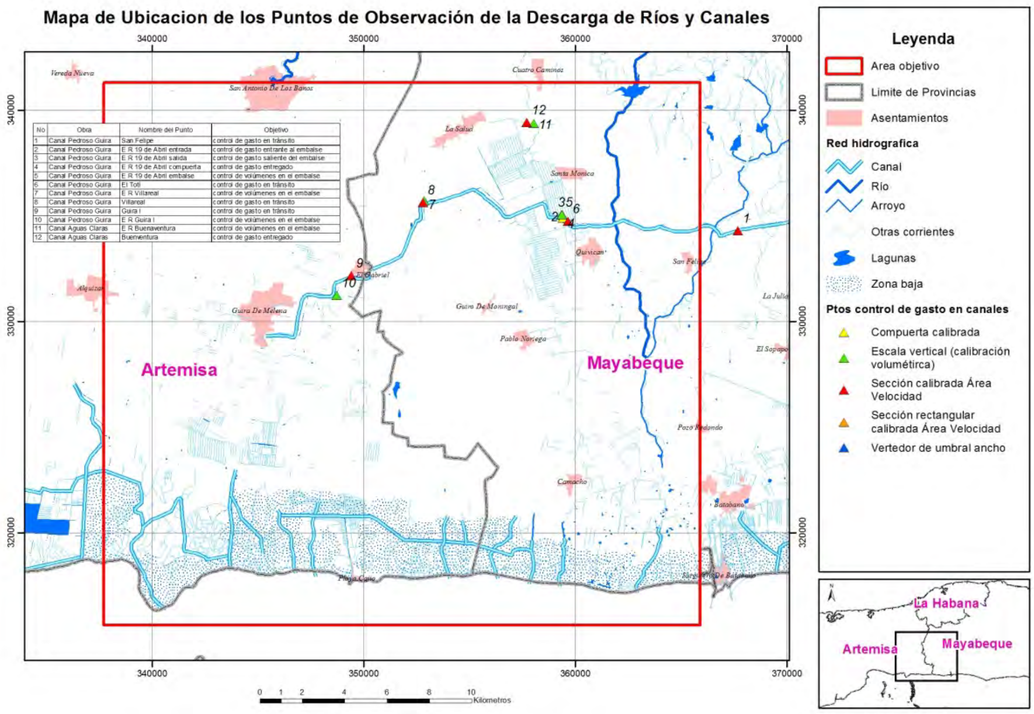

Figure 2-8: Map of the observation points for the discharge of rivers and channels

Table 2-1: Observation points for the discharge of rivers and channels

	Works	Point Name	x	y	Type	Purpose
1	Pedroso Güira Channel	San Felipe	367707	334278	Area-Speed calibrated section	Control of the transit use
2	Pedroso Güira Channel	E R 19 de Abril entrance	359418	335060	Area-Speed calibrated rectangular section	Control of the inflow use of the reservoir
3	Pedroso Güira Channel	E R 19 de Abril salida	359367	335051	Wide threshold spillway	Control of the outflow use of the reservoir
4	Pedroso Güira Channel	E R 19 de Abril compuerta	359419	334900	Calibrated gate	Control of the delivered use
5	Pedroso Güira Channel	E R 19 de Abril embalse	359378	335045	Vertical scale (volumetric calibration)	Volume control in the reservoir
6	Pedroso Güira Channel	El Totí	359842	335736	Area-Speed calibrated section	Control of the transit use
7	Pedroso Güira Channel	E R Villarreal	352856	335713	Vertical scale (volumetric calibration)	Volume control in the reservoir
8	Pedroso Güira Channel	Villaarreal	352826	335626	Area-Speed calibrated section	Control of the transit use
9	Pedroso Güira Channel	Guira I	349438	332170	Area-Speed calibrated section	Control of the transit use
10	Pedroso Güira Channel	E R Guira I	348748	331231	Vertical scale (volumetric calibration)	Volume control in the reservoir
11	Aguas Claras Channel	E R Buenaventura	358050	339383	Vertical scale (volumetric calibration)	Volume control in the reservoir
12	Aguas Claras Channel	Buenventura	357726	339430	Area-Speed calibrated section	Control of the delivered use

2.2 Topography, Geology, Hydrogeology and Groundwater Description

a. Topography

a.1 Introduction

All processes, either natural or induced, that take place on Earth are related to each other, so that any alteration that exceeds the acceptable limits of the variability and dynamics of environmental phenomena, causes a chain of adverse reactions to the environmental system in general. Climate change forced by man’s actions is one of the most significant current events for the environmental balance, precisely because climate is an element, and at the same time a vital resource for the functioning of the planet. However, further progress still needs to be made, including researches, a detailed assessment of how an impact on a given element produces a series of reactions in others, in the same way that an adaptation measure must be assess considering its impact on others sectors.

The territory of the Republic of Cuba has a long and narrow configuration, located at the entrance of the Gulf of Mexico. It is the largest of the Antilles and is made up of more than 1600 islands and islets. The island of Cuba, the Isle of Youth and Cayo Romano are most important ones. It is located between 23º17’, 19º50’ N lat and 74º08’, 84º58’ W long. The Cuban archipelago is also made up of 4 island groups: Los Colorados, Sabana-Camagüey (Jardines del Rey), Jardines de la Reina and Canarreos. The latter is considered to be the most important, as the Isle of Youth is located there, which is second in extension, after the island of Cuba. Boundaries: to the N, the Florida Strait, which separates Cuba from the United States of America by 180 km, and the Nicholas and Old Bahama channels, which separate it from the Commonwealth of the Bahamas by 2.1 km. To the E, the Windward Passage that separates it from the Republic of Haiti by 77 km. To the S, the Caribbean Sea and the Strait of Colon, the latter separates it from Jamaica by 140 km. And to the W, the Strait of Yucatan, which separates it from the United Mexican States by 2l0 km, with an extension of 109 722 km².

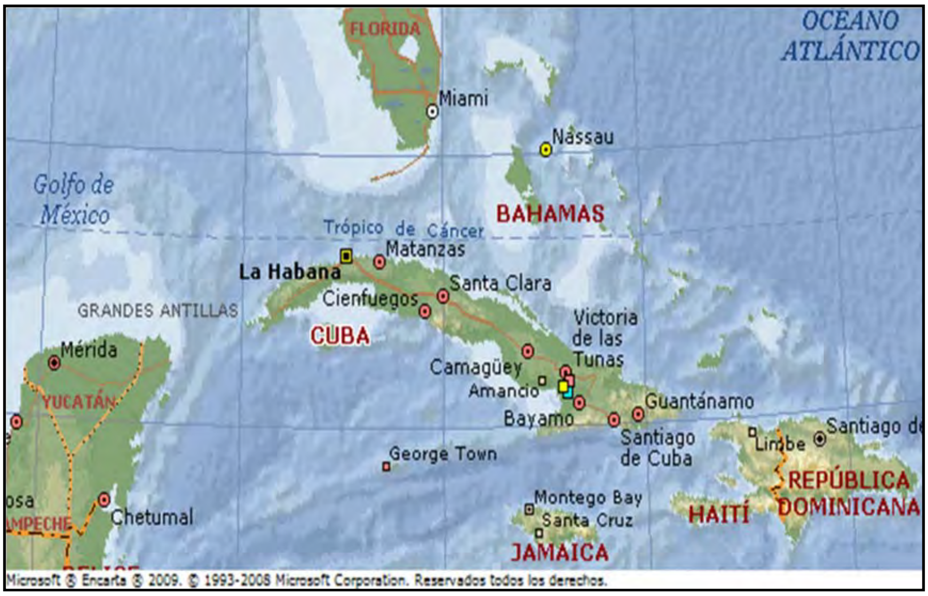

Figure 2-9: Map of the physical and geographic location of the Cuban Archipelago

Figure 2-10: Satellite Image of the Cuban Archipelago

RELIEF, it stands out for its complexity and diversity, constituted by mountains, heights and plains, the latter occupying the larger part of the territory. About 70% has slope angles of 3 degrees and lower. The most important orographic groups are the Guaniguanico mountain range, the mountains of Guamuhaya, the mountains of Nipe Sagua-Baracoa and Sierra Maestra, which are respectively located in the western, central and eastern region of the island of Cuba. The predominant height of the island of Cuba and the Cuban archipelago is Peak Turquino, with 1972 m. In the Isle of Youth, the predominant height is Sierra de la Cañada, with 303 m and in Cayo Romano (third island by its extension), the predominant height is Silla de Cayo Romano with 62 m.

HYDROGRAPHY The geographical situation and the long and narrow configuration of Cuba give it certain peculiarities in the layout of its river network. Among others, a central watershed across the territory stands out. Due to this, there are two sides, North and South. The hydrology of the island of Cuba stands out, because due to the characteristics of the relief and the long and narrow configuration, the main watershed is located at the center and throughout the territory, dividing it into 2 parts: North and South. The length of the rivers and the area of their basins are inferior to 40 and 200 km^2 respectively in 85% of the cases. All of this, linked to the rainfall regime, determines scarce volumes of flow during periods of drought, so it is necessary to regulate them for a later use. The longest rivers are Cauto, Zaza, Sagua la Grande, Caonao and Toa. The majority of the rivers are dammed. The larger reservoirs of the island of Cuba are Zaza and Alacranes. The hydrographic network in the Isle of Youth has a radial distribution and Las Casas river stands out, which is dammed and forms Las Casas Dos reservoir.

a.2 Brief physical and geographic characterization

The province of Havana is a densely populated territory, with a population density of more than 3000 inhabitants per km^2. It also has an extensive agricultural, industrial and tourist development.

The study area is delimited to the North by the Heights of San Antonio de los Baños and Bejucal, to the West and East by the continuation of the plain and to its Southern portion by the waters of the Gulf of Batabanó.

Topographic elements are characterized by a marine plain that presents morphological steps where features of abrasive-denudation-dissection and cumulative processes can be seen between spot heights of 5-10 m, 10-20 m, 20-80 m and over 80 m.

These processes were developed on carbonate sediments of the Neogene that evolved to a denuded karstic plain with a width of 15-20 km, with variation of absolute spot heights of 1.00 - 40.00 m above the sea level (E. Rocamora, M. Guerra and E Flores, 1997).

The river network is scarcely represented by the rivers or streams of Capellania, San Antonio de los Baños, Quivicán and San Felipe.

Figure 2-11: Planimetric map of the study area representing the villages, the river network and the regional morphology

The target area occupies the Artemisa-Quivicán sub-basin, located in the central area of the Southern end of the provinces of Havana, Artemisa and Mayabeque, belonging to the Cuenca Costera Sur (sourthern coastal basin), located at coordinates X: 316.912 - Y: 348.095 and X: 313.018 - Y: 317.986 with an approximate surface extension of 1041 km^2, where the villages of Artemisa, Alquizar, San Antonio de los Baños, Güira de Melena, La Salud, El Gabriel, Quivicán and others. Its borders to the East on the Batabanó underground basin, to the West on the Corojal Basin and the Northern area of Artemisa, to the South on the Gulf of Batabanó, and to the North on the Ariguanabo y Mampostón Basin. The region is a denuded karstic plain with a width of 15-20 km, with variation of absolute spot heights of 1.00-40.00 m over the sea level. Soils are of the red ferralitic type, with very good drainage and high productivity. A fragment of the Geomorphological Map corresponding to the Artemisa-Quivicán sub-basin is shown below.

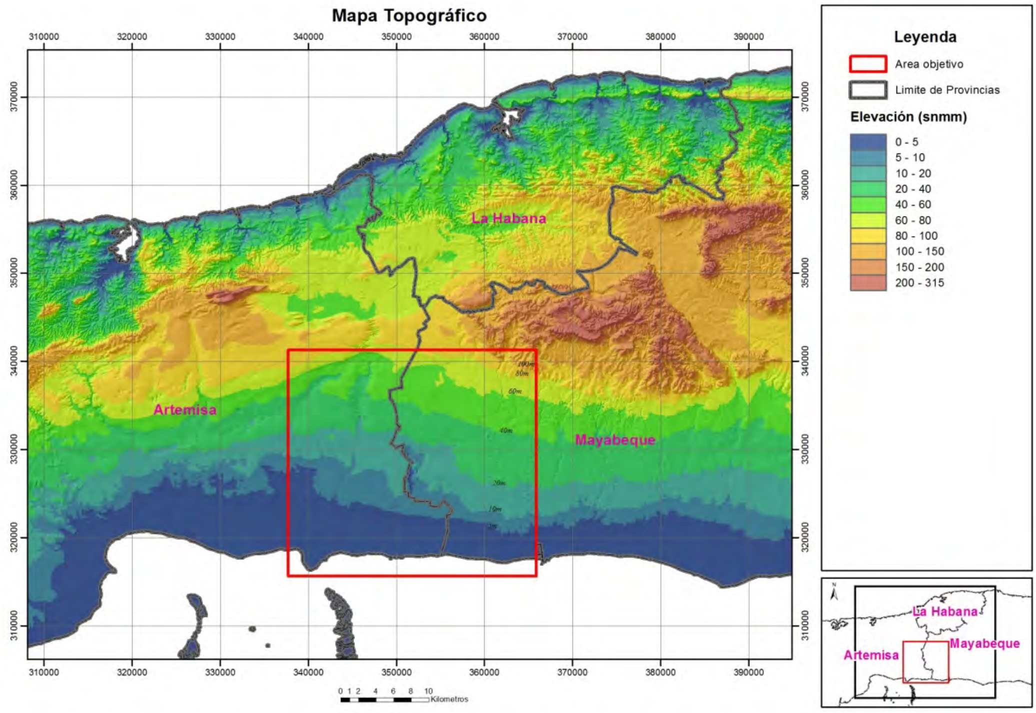

Figure 2-12: Topographic map showing the different altimetric surfaces

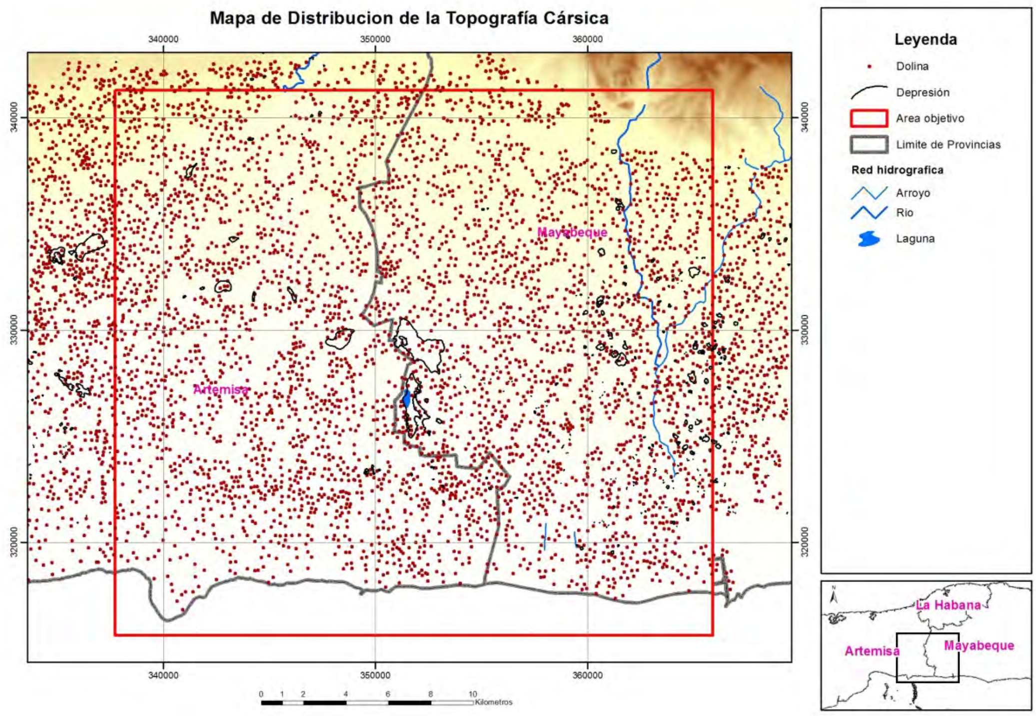

Figure 2-13: Distribution map of the superficial karstic forms

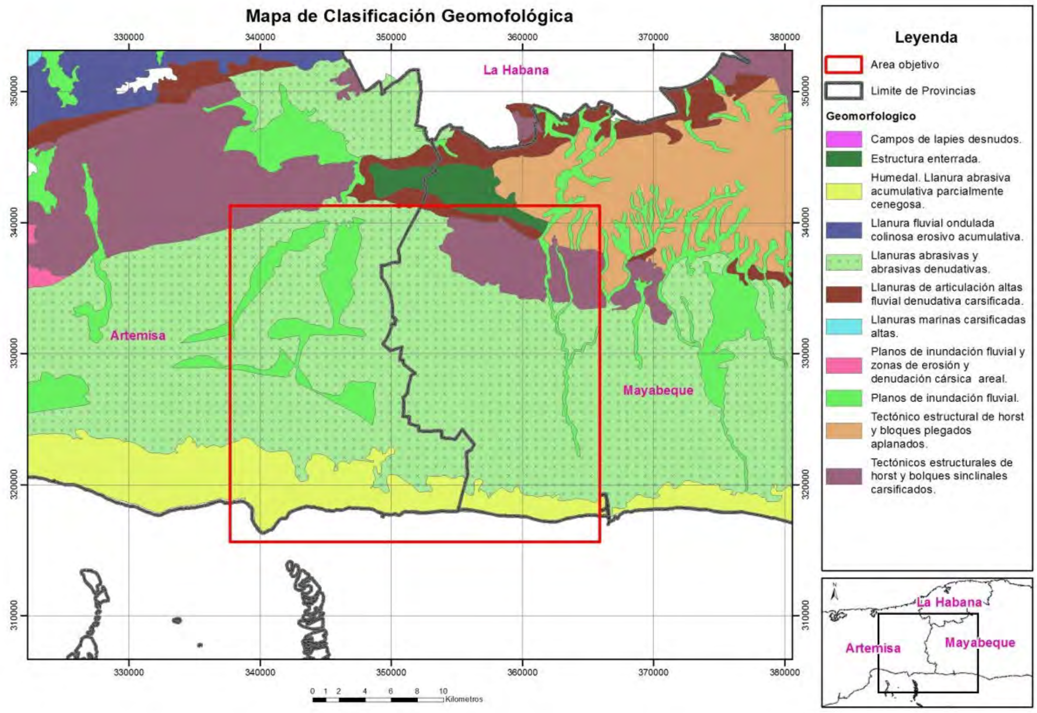

Figure 2-14: Map of the land classification

b. Soils, Vegetation and Land use

b.1 Introduction

The project area is characterized by the presence of argillaceous sandy soils of the red ferralitic types, lying on carbonate rock complexes.

Areas of limestone appearing on the surface are found scattered throughout the territory. Soils are less developed in the Northern elevations, whereas more developed clayey soils stand out in the plain with a power between 0.50 to over 1.50.

The vegetation shows different types of forests, bushes, herbaceous, mangroves and complexes of diverse cultures. Despite the number of existing species, only a few hundred native plants are used for economic purposes, mainly for forestry and medicine.

b.2 Soils

The predominant soils in the study area, according to the New Version of the Genetic Classification of Soils in Cuba (Institute of Soils, 1999), are those belonging to the ferralitic groups with predominance of the red ferralitic type as well as red ferralic soils, with the typical and compressed subtypes in both cases, and in third place the leachate yellowish ferralitic type with the typical and glacial subtypes (those that occupy as a whole, more than 80% of the total area of the sub-basin). Other soils of the area are those of the sialitic brown group (ochric brown and hoed brown types) that appear occasionally combined with soils of the rendzina type, occupying a little over 4% of the total area.

Soils of the histosol grouping (peat soils), represent a special case, associated to wetland areas of the Ciénaga Sur de la Habana (Southern swamp of Havana), which occupy around 9.5% of the sub-basin area (Figure 2-15).

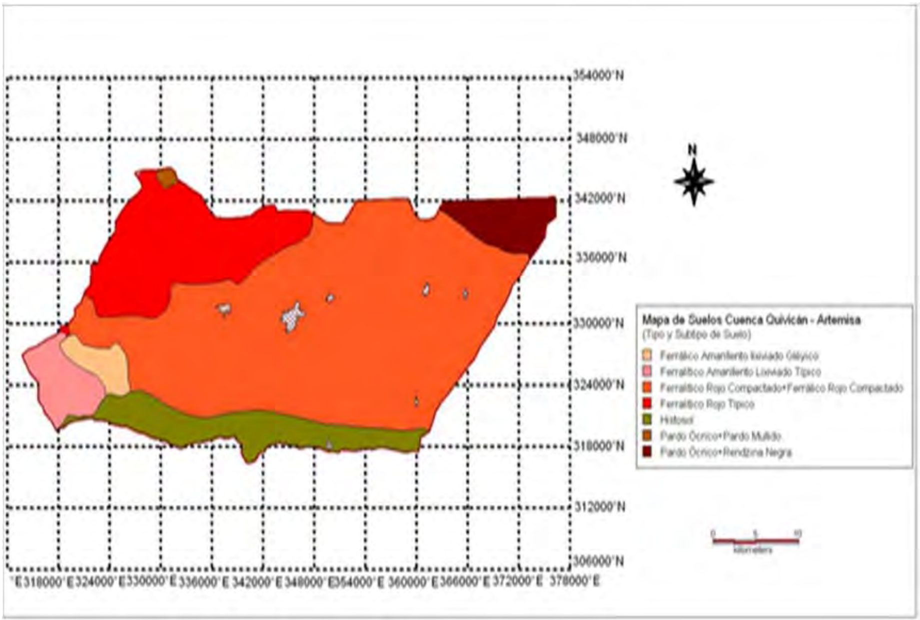

Figure 2-15: Map of the predominant soils in the study polygon

TYPES OF SOILS: With respect to the main types of soils, the most representative soils are ferratic red + compacted ferratic red with an area of 708.23 km^2, representing 61.6%.

Table 2-2: Types of soils and area

No	Type and subtype of soil	Area (km^2)	%
1	Ferratic red + compacted ferratic red	708.23	61.6
2	Typical ferratic red	198.17	17.2
3	Coastal swamp with predominance of histosol	109.27	9.5
4	Ochric brown + black rendizna	50.3	4.4
5	Typical leachate yellowish ferralitic	47.97	4.17
6	Leachate gley yellowish ferralitic	25.3	2.2
7	Ochric brown + hoed brown	3.4	0.3

b.3 Vegetation

The target area presents a vegetation constituted by agricultural crops that occupy a great part of the territory, tubers and vegetables among them, such as: *Solanum tuberosum* L. (potato), *Ipomoea batatas* (L.) (sweet potato), *Manihot utilissima* Crantz (cassava), *Lycopersicon lycopersicum* (L.) (tomato), Karsten, *Capsicum annuum L*. (chili), *Cucumis sativus* L. (cucumber), *Abelmoschus esculentus* (L.) Moench. (Okra) y *Raphanus sativus* L. (radish), among others. Forest plantations are constituted by *Albizia* sp. (musician), *Casuarina equisetifolia* Forst (casuarina), *Calophyllum antillanum* Britt. (beauty leaf), *Hibiscus tiliaceus* L. (majagua tree) y *Leucaena leucocephala* Witt s. (ipil-ipil). In the farms, there are also fruit plantations of *Annona muricata* L. (soursop), *Annona squamosa* Delile (sugar-apple), *Citrus* sp. (Citrus species), Cocos nucifera L. (coconut) Mangifera (Mango), Musa paradisiaca L. (fruit banana, tuber banana), Persea americana Mill. (avocado), Psidium guajava L. (guava), Pouteria manomosa (mammee), Pouteria sapota (sapote) y Tamarindus (tamarind). Uncultivated areas are covered by secondary bushes with a height of 5 to 6 m and a large presence of thorny species such as Dichrostachys cinerea Africana (introduced marabou) and Acacia farnesiana (L.) Willd. (yellow aroma, aroma), among others, which make them impassable.

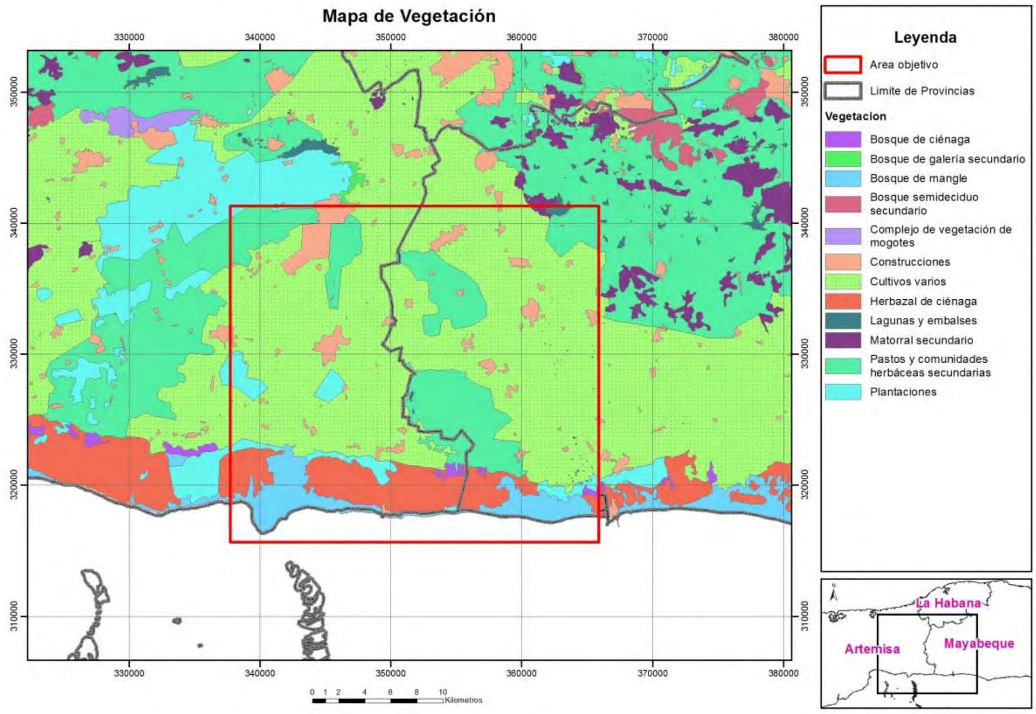

Figure 2-16: Map of the types of vegetation present

b.4 Land use

The land use in the area of the project, comprising the provinces of Artemisa and Mayabeque, is predominantly for agriculture; although it has an incipient industrial heritage as well as a large number of towns and villages where the population lives.

The area has urban settlements as the four municipal centers: San Antonio de los Baños, Alquízar, Güira de Melena, Quivicán and Batabanó as well as the towns of La Salud, El Gabriel, San Felipe, Camacho, Guanímar and Cajío among others.

As to the industrial use, agricultural industry is predominant, and the main ones are such as sugar came mills, agricultural equipment factories, industrial furniture factories, construction material industries (quarries), canned food factories and tobacco processing factories.

As it is a preferably agricultural area, about 90% of the use of land is for crops, mainly: sugar cane, assorted crops (tubers, vegetables, grains, rice, bananas), tobacco, citrus, etc. The land is also used for livestock, poultry and pig raising.

There are extensive areas dedicated to reforestation, a coastal strip, of about 2 km of wetland wide, where mangroves predominate and a swamp forest, where a forest of scrubland predominates (Figure 2-16).

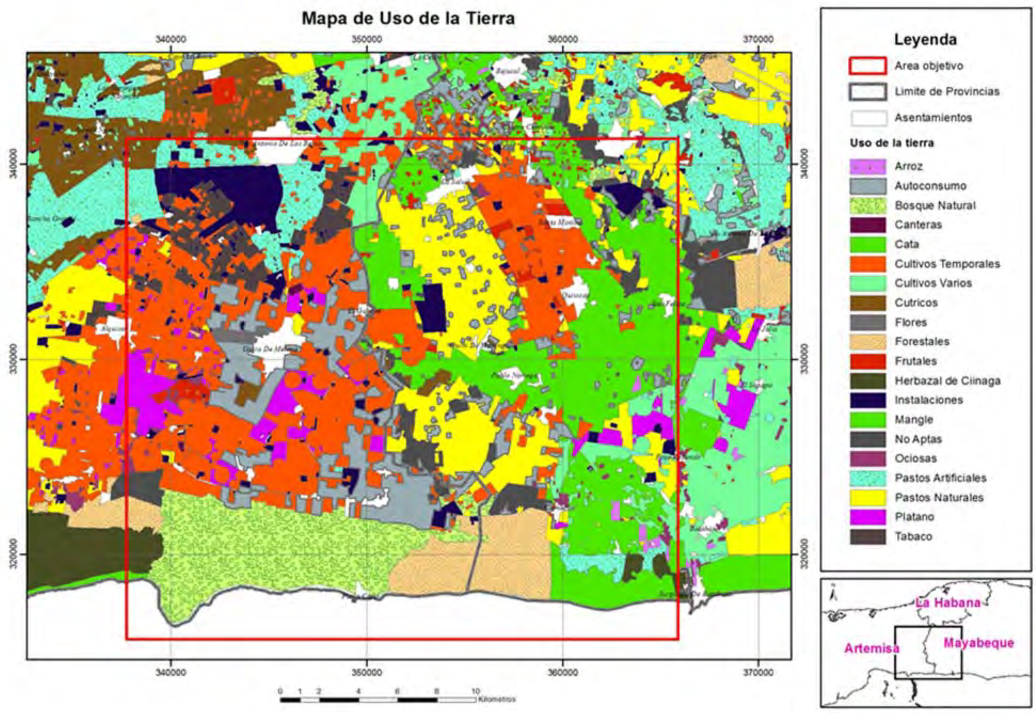

Figure 2-17: Map of the land use

c. Geology

The target area of the JICA Project has Neogene rocks that, from a stratigraphic point of view, are divided into a series of formations that differentiate among themselves by their composition and lay conditions in different structural areas: Cojímar, Colón and Güines formations. As to lithology, they are mainly different types of limestones: reef, cavernous, crystalline and dolomitic (Figure 2-18).

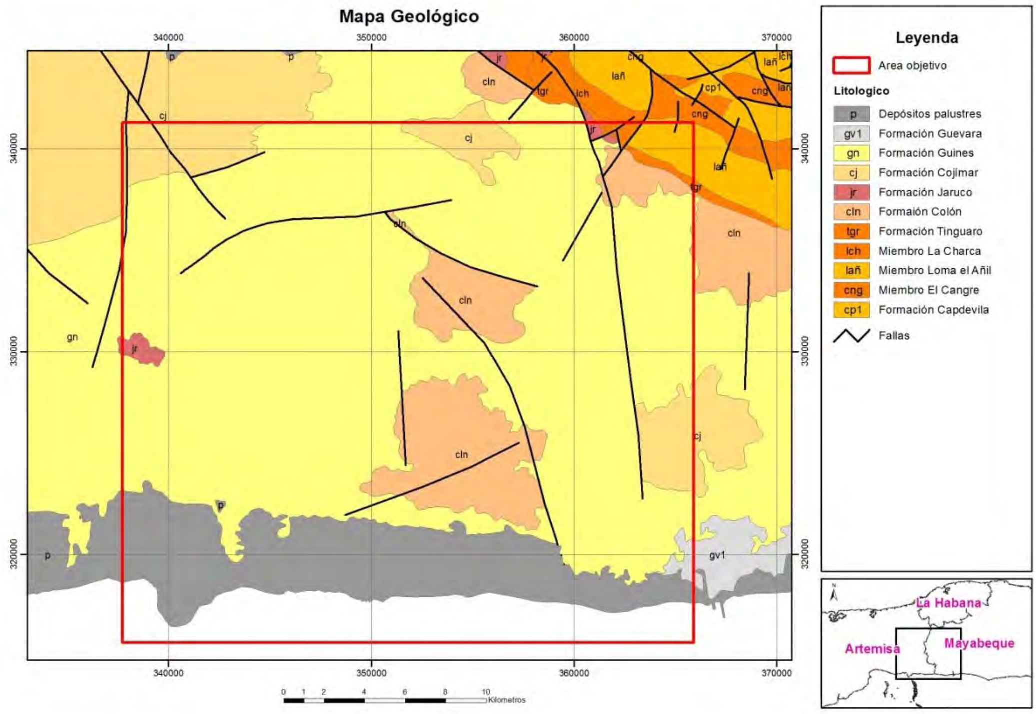

Figure 2-18: Geological map (IGP, group of authors, 2001)

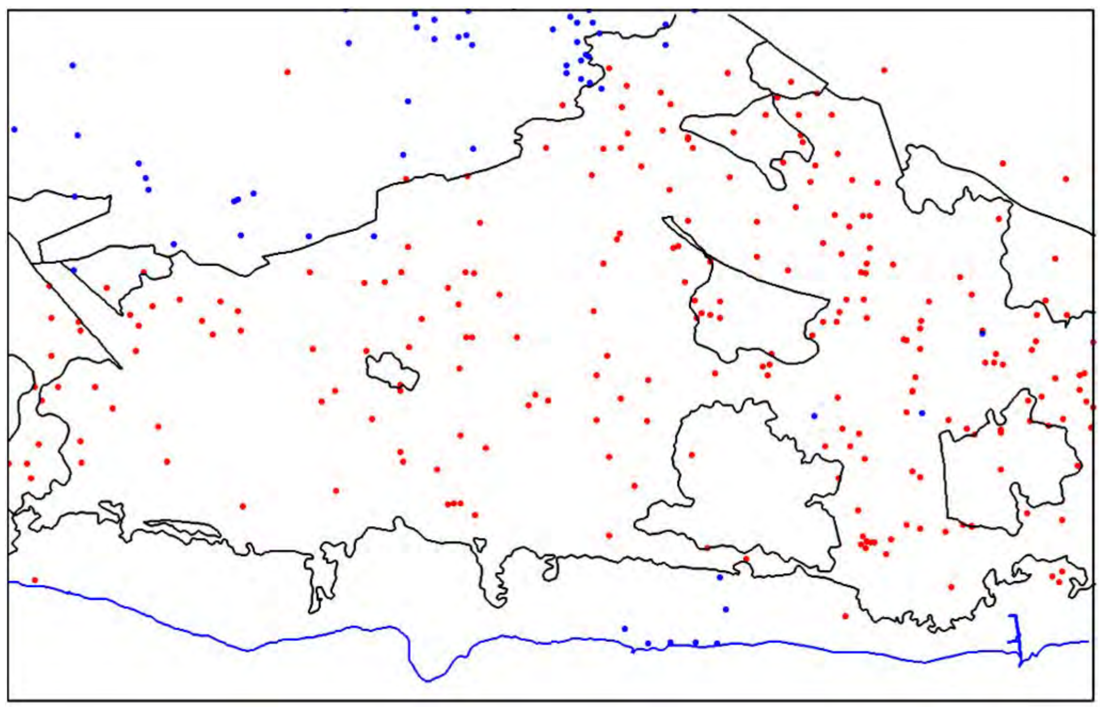

Figure 2-19: Database map of bores and wells with lithologic description (L. Valdés, 2016)

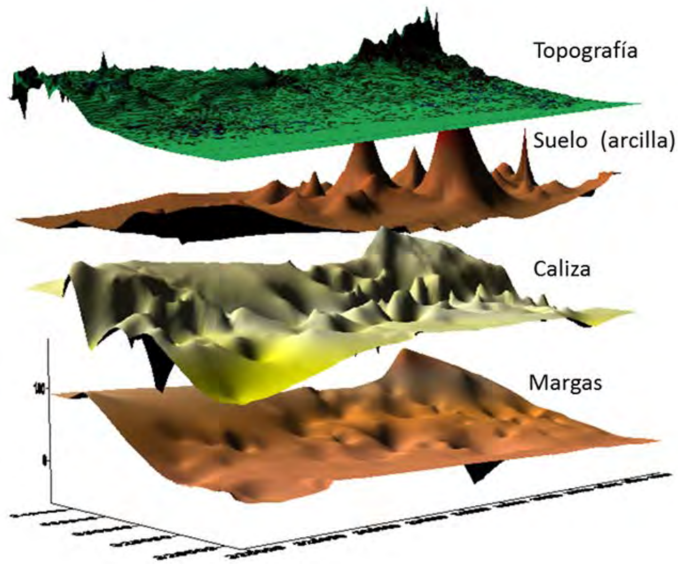

Figure 2-20: Schematic block of the structural morphology in the study area. (E. Flores, 2016)

To the North, around the town of San Antonio de los Baños, coinciding with the groundwater dividing lines by the drillings in the **Cojímar Formation**, cream-colored clay limestone and gray marlstones appear, considered as almost impermeable by their low wateriness. The description of the formation (stratigraphic lexicon Cuban Academy of Sciences (ACC for its Spanish initials)) is the following:

Cojímar Formation (cj)

- **Geographical distribution**: It developed in the provinces of Havana, Artemisa, Mayabeque, Matanzas and Pinar del Río.
- **Lithologic composition**: Calcareous marlstones, argillaceous, arenaceous, sometimes nodular, chalk, clay biodetritic limestone, calcarenites of marly matrix and clays. Predominant colors are cream, yellowish, whitish and greyish.
- **Age**: Its fauna allows to date it as Lower Miocene in the high area and Middle Miocene in the low area (N_1^{1-2}).
- **Thickness:** Between 60 to 390 meters.

The flat area to the South, which is slightly leaning towards the coast, shows in general limestone of the **Güines formation**, developed in a shallow marine environment. They are constituted by organogenic, recrystallized, creamy-white sandy limestone, which in some places transition to light gray dolomitic limestone. The limestone present different degrees of karstification and small strike angles to the South of the Güines formation, developed in a shallow marine environment.

Deep bores have allowed to determine the presence of highly karstified layers up to the depths of 150 to 230 m. A high degree of karstification is a characteristic of this formation. A system of pipes, caverns and cavities that are usually related to each other crosses the karstified horizon, by area and thickness and conditions the immediate hydraulic relationship of the groundwater in the vertical and horizontal direction.

The diameter of the cavities varies, from small pores to caverns of tens of meters. Cavities are either empty or filled with the sandy limestone material (calcareous mudstone). Due to the intense karstification, frequent falls of the drills occur when making bores.

The karstification degree also varies in the cut. Generally, the largest number of cavities is located at the top and it decreases with the depth. According to the results of resistivimetry with the salinization in the wells, areas with a high filtration rate have been determined, that is to say, areas of high cavernosity.

Until now, it has not been possible to determine the real dependence of the karstic development in the vertical and horizontal direction for the studied area.

The description (according to the description of the Cuban Academy of Sciences (ACC by its Spanish initials)) is as follows:

Güines Formation (gn)

- **Lithologic composition**: Fine-to-medium-grain biodetritic limestone, fossiliferous, biohermal, dolomitic limestone, dolomites, micritic and saccharoidal limestone, and occasional lenses of marls and calcarenites. Dolomitization has a secondary nature. Limestones are usually massive, rarely stratified. Colors vary from white, yellowish, cream and gray.
- **Age:** Middle Miocene in the high area and Higher Miocene.
- **Thickness:** It varies between 50 and 1670 m.

There are blocks that come to the surface to **the North and South of the town of Quivicán** that belong to the **Colón formation**, which lies concordantly below the Cojímar and Güines formations. It formed in a shallow sea by transgression processes. It is represented by organogenic limestones, compacted and clayey, calcareous marls in some places. The description given by the Cuban Academy of Science (ACC) is as follows:

Colón Formation (cln)

- **Geographical distribution**: It developed in the provinces of Cienfuegos, Havana, Artemisa, Mayabeque and Matanzas.
- **Lithologic composition**: It is comprised of five facies in general.
    1. biocalcarenites and fine biocalcirudites of marl nuance, fine calcirudites of micritic nuance.
    2. biomicritic limestones.
    3. polycrystalline sandstones calcareous-clayey to clayey-calcareous nuances.
    4. Marls.
    5. calcilutites that are inter-sratified with calcarenites and calciudites.
- **Age:** Late Oligocene, in the high area Lower Miocene.
- **Sedimentation environment**: It was deposited in a deep sub-littoral environment with some reef development. It is possible that some packages have been deposited in the infra-littoral zone.

- **Thickness:** It does not appear to exceed 65 m in the type area according to the data collected from wells.

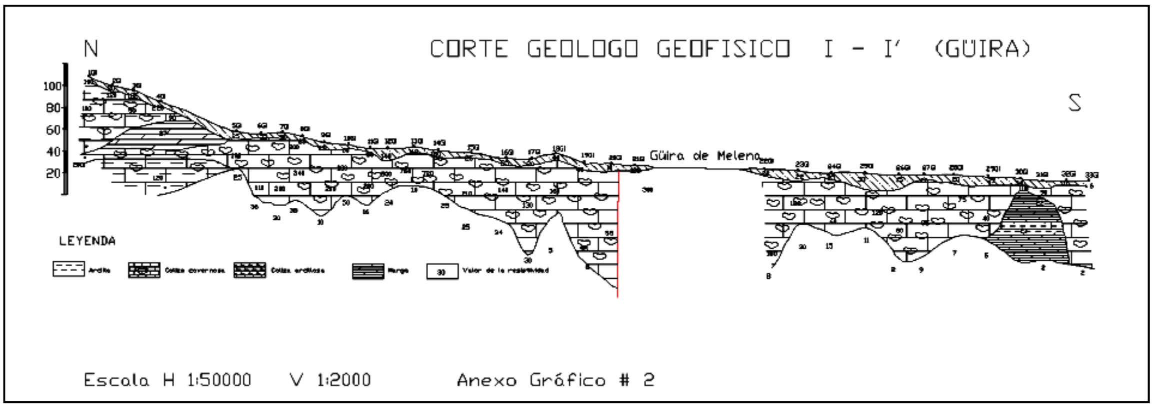

Figure 2-21: N-S geophysical profile of the morphological structure and lithology of the basin, from Altura de San Antonia to the village of Junco. (N. Piñero, 1980)

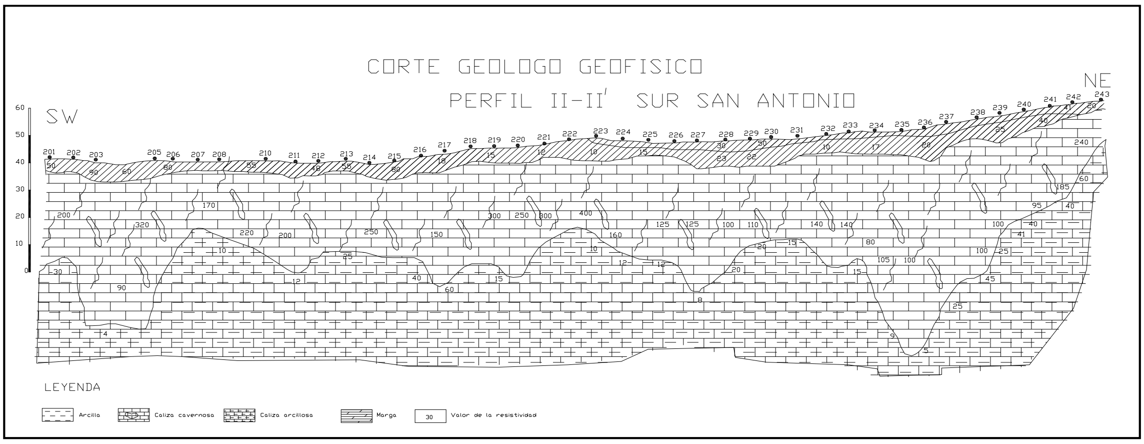

Figure 2-22: SW - NE geophysical profile of the morphological structure of the basin. To the S of the town of San Antonio de los Baños, we can see the variation between two lithologies and the zone of density for the development of karst. (N. Piñero, 1980)

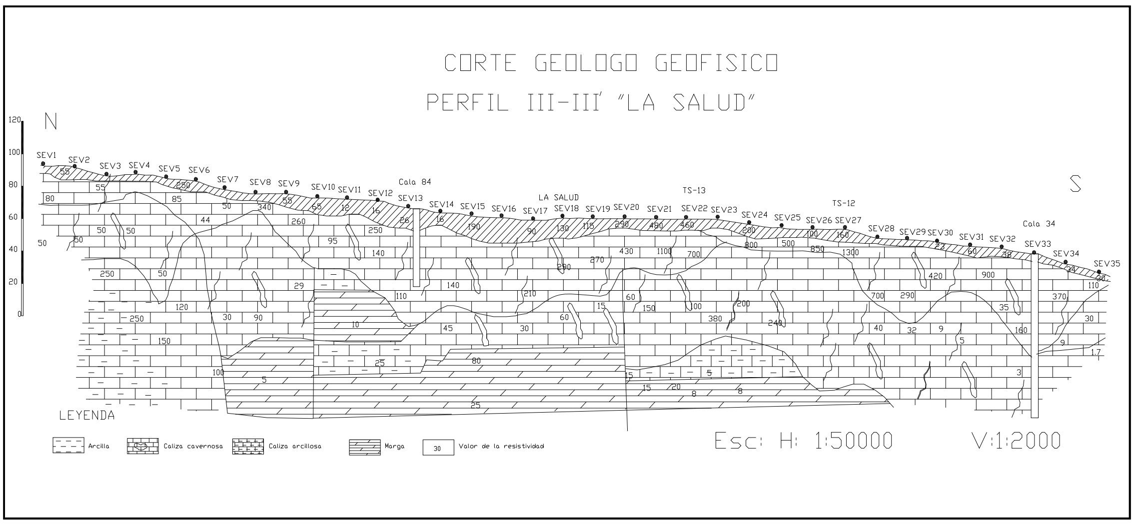

Figure 2-23: N - S geophysical profile of the village of La Salud, which shows the geological and structural complexity of the basin. (N. Piñero, 1980)

Quaternary: All these formations are covered by yellowish red eluvial clays with fragments of limestone. Its power is variable, although it can reach up to 20 m, perhaps due to the collapse of caves. There is a swath of muddy alluvial sediments of clay with organic matter and clay peat soils in the coastal zone.

The area belongs to the tectonic facial meridional zone, characterized by a system of layered faults towards the sea where the graben of the Gulf of Batabanó is formed. The region is a monocline structure with a strike angle towards the sea with a slope between 5º and 10º.

The rocks in the Neogene, were submitted to tectonic movements and were mainly characterized by subsidences, as the upliftings, in general, were not remarkable. During the Pliocene and Pleistocene, upliftings occurred throughout the island, as well as transgressions and regressions. It is estimated that the karst development begins at this age.

KARST: Karst processes in the Cuenca Sur study area of Artemisa and Mayabeque began its evolution at the end of the Pliocene when the physical and geographical conditions for the karstic development were already created, in the lithological, tectonic and hydrological order (Figure 2-24). Tectonic processes during the late Pliocene and in the Quaternary, have defined a turnover network with preferential directions and densities in which different stages and families of the tectonic structure can be seen (Figure 2-25). Predominant families have directions 60 and 150 with a perpendicular relationship between them. They govern the sense of the karstic development, and those remaining are the ones that configure the solutions of discontinuity for the caverning three-dimensional expansion.

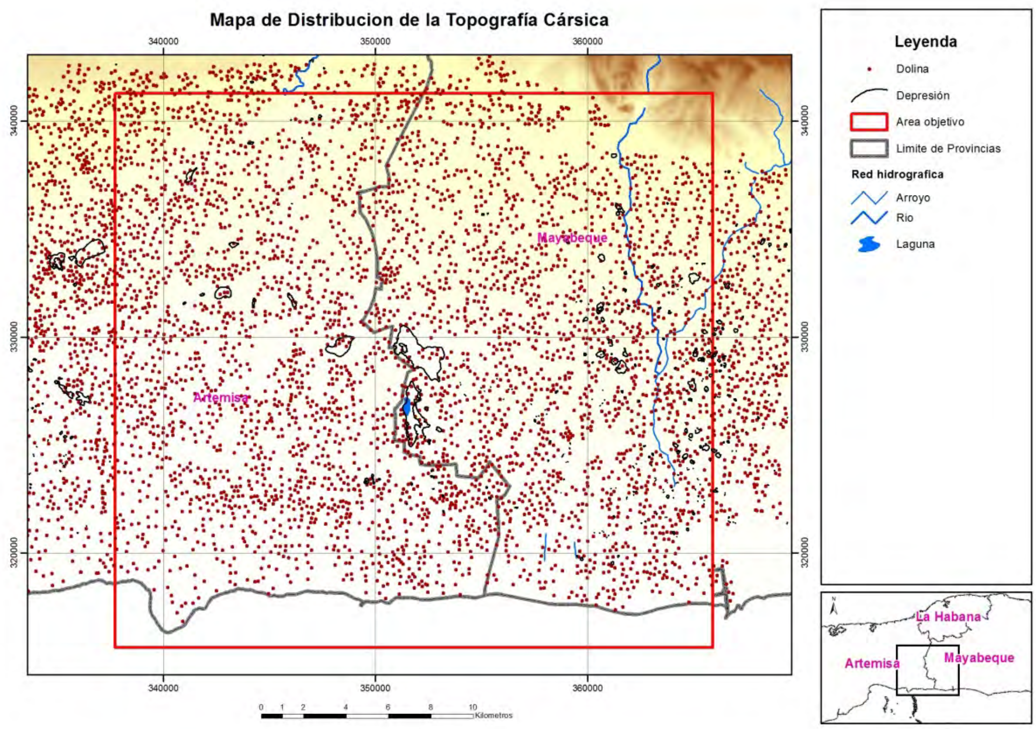

Figure 2-24: Map of the karst surface development in the Cuenca Sur, HS III and HS IV Sections. (C. Behцkebич, E. Flores, 1997).

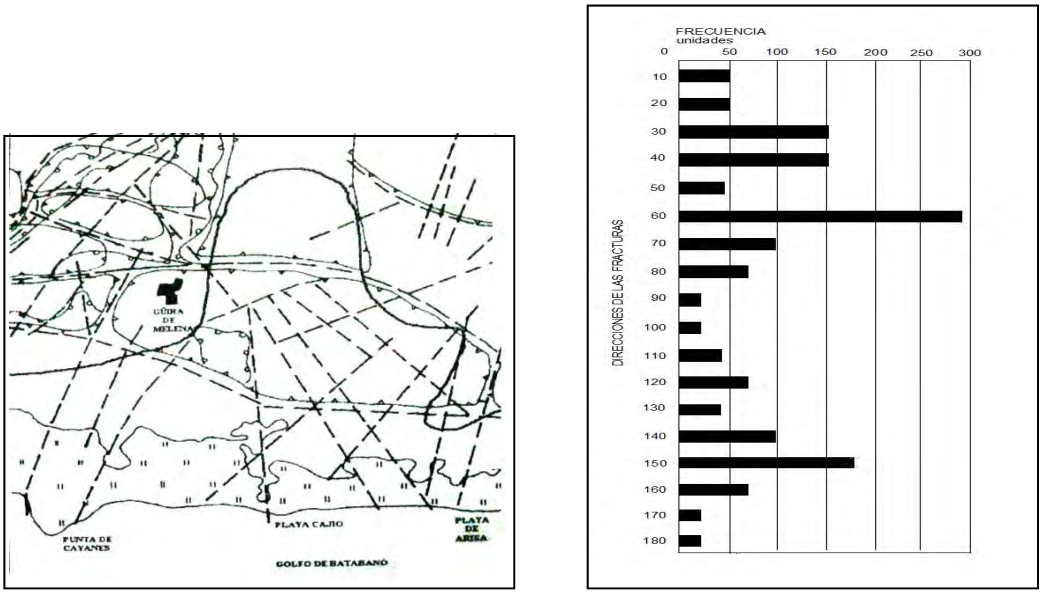

Figure 2-25: Mapa de las aliniasiones estructurales y de ladirecciones predominante (E. Racmora, M. Guerra, E. Flores, 1997)

Processes of karstification are evidenced both in the surface and in the depth. Examples of it are the fields of limestone pavements, drains and karst depressions as dolines, uvalas and poljes. These karstic forms make up infiltration systems of the superficial waters to the aquifer, carrying out a natural recharge (Figure 2-26 to Figure 2-29).

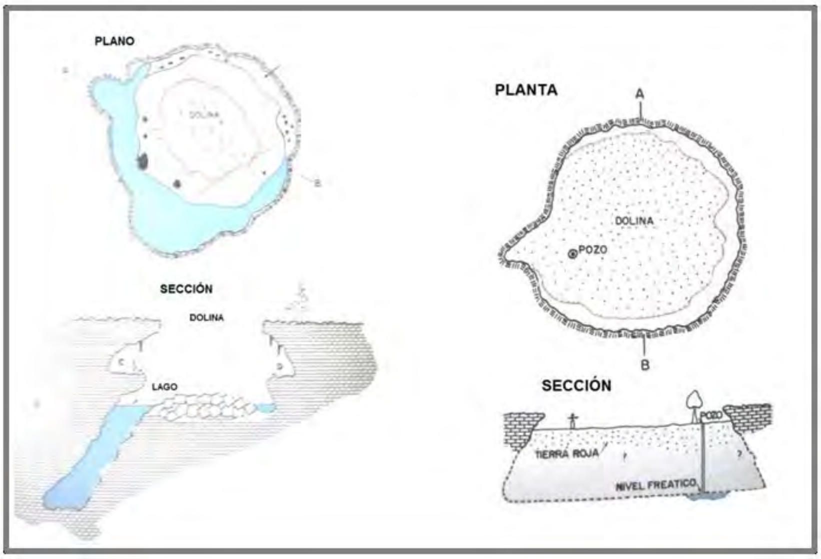

Figure 2-26: Scheme of the dolines of a diameter on the left the Cueva de la Lechuza, cavity with three erosive levels and contact with the aquifer. To the right, the Cueva de San Isidro, doline is filled of clay sediments. Both of them belong to the Artemisa prov. (A. Nuñez Jimenz, 1967)

Underground karst forms belong to the cavern type (vertical ducts), networks of galleries (horizontal or with some slope). They are the pipes for groundwater storage and conduction (Figure 2-27).

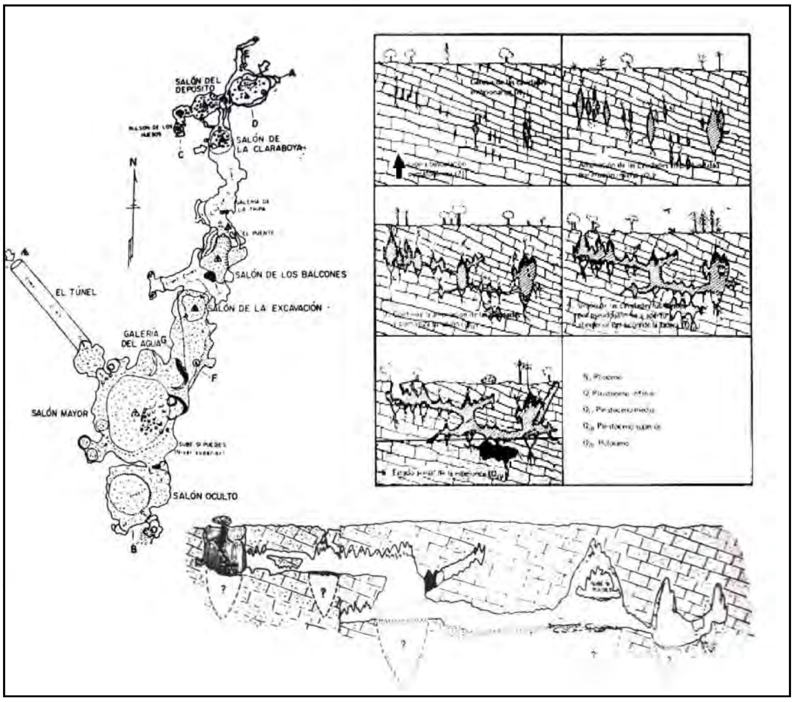

Figure 2-27: Evolutionary scheme of the Cueva del Túnel, Mayabeque prov., the cavity presents a development from N to S starting from the union of several families of fissures. It displays fourth well defined caverning levels (M. Acevedo and others,1984 in A. Nuñez Jimenez, 1984)

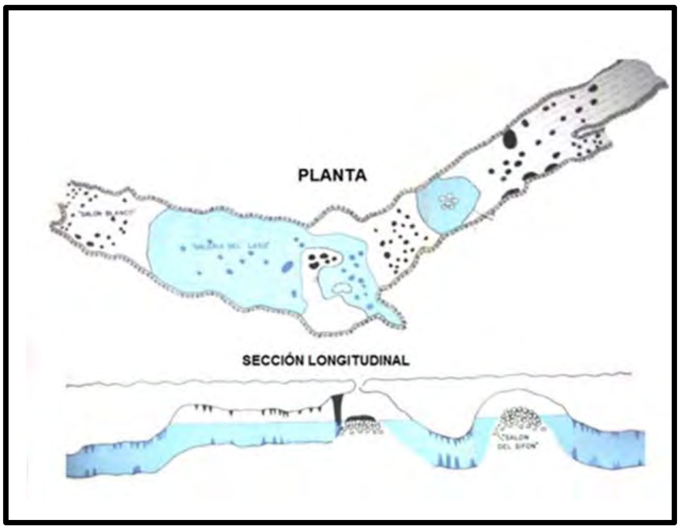

Figure 2-28: Scheme of the Caverna Juanelo Piedra, re-flooded cavity. (A. Nuñez Jimenez, 1978)

Figure 2-29: Views of the Caverna Juanelo Piedra, cavity re-floded in the last interglacial of the Holocene. The photos show the level of the aquifer in the entrance hall and the flooded gallery. (E. Flores, 2014 and A. Nuñez Jimenez, 1978)

Emissive karstic forms that can be found in the Project areas are breathing holes or cavities where groundwater re-emerge after a journey of tens of meters to kilometers and karstic springs originated due to the positions of the current or previous discharge levels (Figure 2-30).

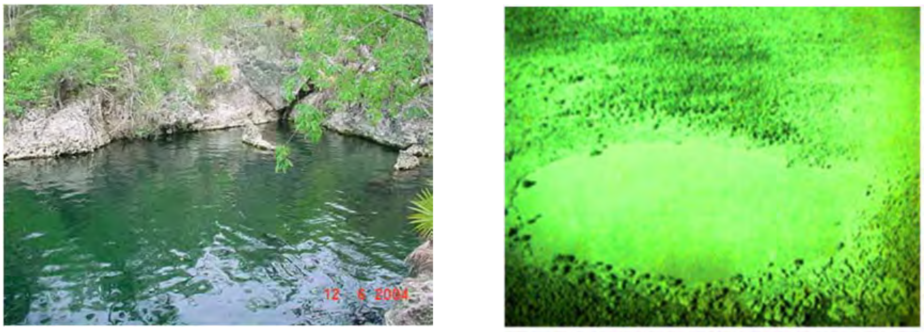

Figure 2-30: Dolines and flooded caverns are the most common forms of discharge in the southern plain of Artemisa and Mayabeque. To the left there is a preferential pipe and to the right one of the many emissive dolines that abound in the wetland strip. The aquifer discharges by either form

COMMENTS ON THE KARST

The current complex of karst forms is the result of the evolution of dissolution processes, mechanical erosion and collapse of an underground drainage network directed by the solutions of discontinuity in the tectonic structure and the different lithologies forming the basin, as well as the fluctuations of the mean level of the sea during the Quaternary. The graph of bar A represents the different levels reached by the sea in the Northern Hemisphere and the Gulf of Mexico, as well as the times that these levels were occupied (frequency) and Graph B shows the caverning levels reported for the island of Cuba. Graph C represents the caverning levels in the Cuenca Sur of Artemisa and Mayabeque.

It can be seen that the reiteration of regional levels of the sea conditioned an intense karstification between the 150 m spots height above mean sea level (mamsl) and -80m below mean sea level (mbmsl). In the Llanura Sur of Artemisa and Mayabeque this sequence is seen in the network of karstic galleries and cavities, and its frequency predominates between the spots height of 40 mamsl and -55 mbmsl.

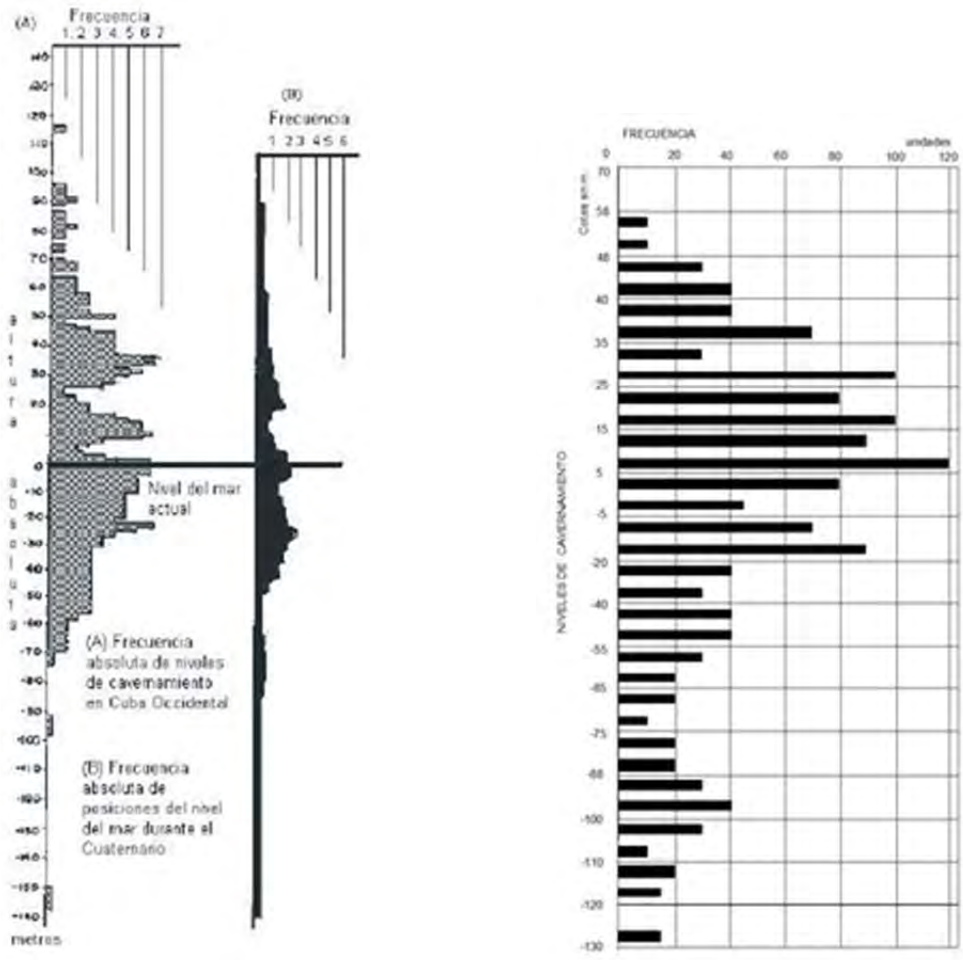

Figure 2-31: Bar graphs depicting the frequency of the positions of the mean sea level in the Quaternary (from Nebraska to the Holocene, A). B shows the caverning levels on the island of Cuba and C shows the caverning levels in the LLanura Sur of Artemisa and Mayabeque

Karsification not only occurred in this range of spots heights, at superior heights and at greater depth, karstic erosion continues but on a smaller scale, in the upper spots height caverns are found with limited development or mere fossilized, fields of limestone pavements, drains and dolines linked to the feeding area.

The high density of superficial karstic forms led to the dismemberment of the river drainage network and to the appearance of endorheic network systems in the main depressions, thus forming the natural recharge of the current aquifer.

The natural discharge of the aquifer is carried out by multiple and diffuse springs as well as by cavern levels between -10 and -35 m on the platform of the Gulf of Batabanó.

The zone of fluctuation and circulation of the water of the aquifer is located between the spot heights of 25 to -30 m. Caverning levels between spot heights -35 m to -40 m facilitate seawater intrusion. Measurements carried out in the monitoring of the salinity in the Cuenca Sur shown that the depth is predominant and reiterative between -30 and -40 m as a limit of freshwater – saltwater.

d. Hydrogeology

The research area of the project comprises part of the two hydrogeological sections of the southern coastal area: Artemisa-Quivicán (HS-3) and Batabanó (HS-4).

The Neogene aquifer complex has been studied to a depth of 200 m although there are some deeper wells. As an example, we can mention the bores drilled by the MINBAS (Spanish acronym for the Ministry of Basic Industry), for the Aguas Profundas (deep waters) project, which are located in the central part of the section and reach a penetration in the aquifer of 540 m.

According to these *drillings* the Neogene aquifer complex can be divided into two horizons: first, an upper one, with a thickness of up to 200 m, mainly represented by karstified limestones from the Güines formation with transmissivities of 1 000 to 10 000 m^2/d and in some cases, even over 10 000 m^2/d. Second, a lower one, up to 500 m, represented by less karstified organogenic limestones *of* lthe Güines formation and by transition clay limetones from Güines to Cojímar, with transmissivities lower to 100 m^2/d.

The lower limit of the Neogene aquifer complex has not been determined, but, according to the research carried out so far, it is possible to consider it over 500 m. Nevertheless, the thickness of the actually active zone of the Neogene aquifer coincides with that of the freshwater, which is 40 to 50 m.

Taking into account the particularities of the groundwater regime in the Neogene aquifer complex, it is possible *to divide it* into two main areas. **A first area** that extends to the North, from the dividing line of the underground runoff to the hydrohypse +5. In this part, the oscillations of the levels vary in a hydrological cycle of 2 to 5 m, where the spot heights of the groundwater levels are of 5 to 100 m and the flow gradients of 0.002 to 0.006 and, in the pre-mountain area, of 0.04. **The second area** extends to the South from the +5 hydrohypse to the boundary with the saltwater, forming an approximately semi-circular hydrogeological structure limited by faults. The amplitude of the levels in this area is not greater than 1 m in a hydrological cycle and only when heavy rainfall occurs can reach a maximum of 4 m. The flow in this area is practically flat, and the minimum gradients reached values below 0.0001.

The underground flow generally runs towards the sea, but in the area of the Cuenca Sur Aqueduct, due to its influence, the flow runs towards the northwest-southeast.

Distribution of hydrogeological parameters

The results of pumping tests performed on thousands of wells, have only allow to determine the coefficients of Conductivity, Transmissivity and the calculation of the specific capacity, with which regionalization plans have been made in the Specified Regional Scheme completed in the year 1991. However, very few tests were carried out with the observation wells, so the regionalization of the storage coefficient cannot be obtained.

The division into zones of the specific uses has a very close correspondence with the stratification of the Neogene deposits in the area. This is manifested by an alternative distribution of specific use in the same direction, ranging from 10 to 50 l/s, higher than100 1/s and again from 10 to 50 L/s.

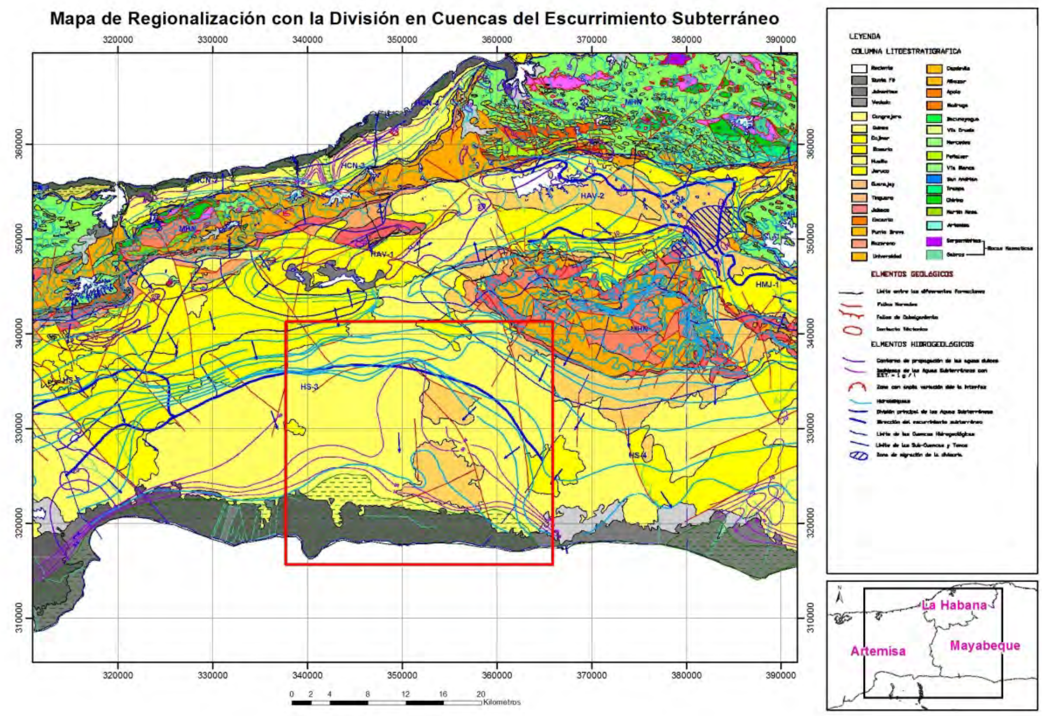

Figure 2-32: Regionalization map with the basin division for the underground runoff

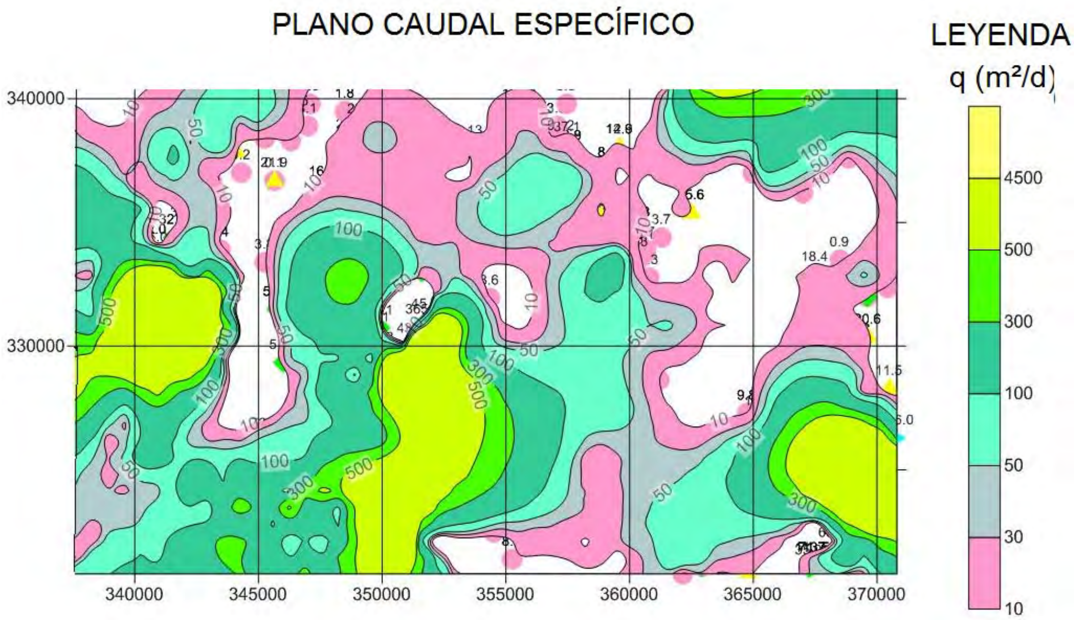

Figure 2-33: Plane of the specific flow

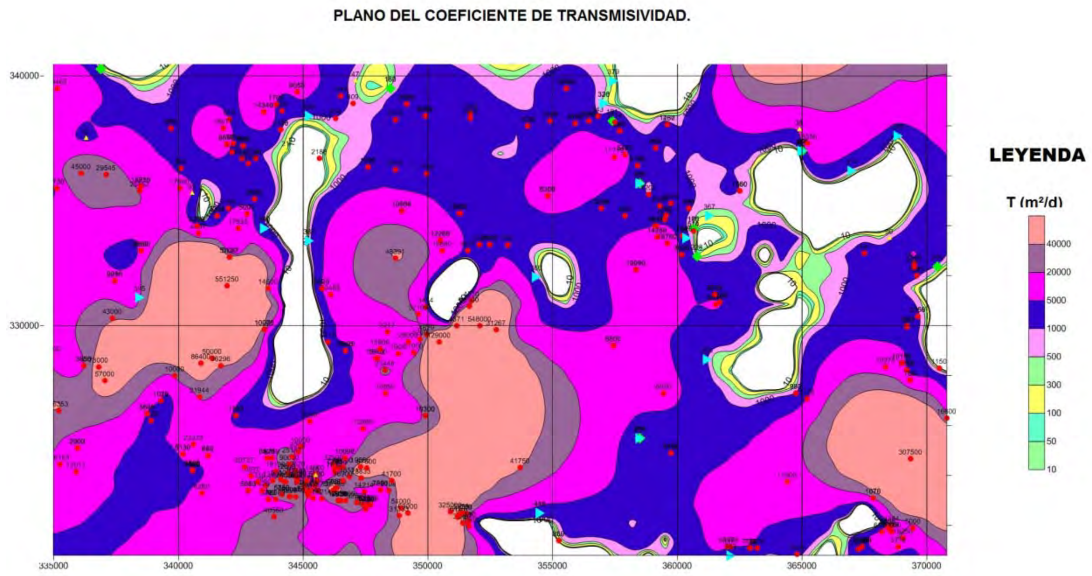

Figure 2-34: Plane of the transmissivity

Carrying out of the pumping tests in the JICA 2 and 3 wells

For each well, a stepped pumping test was scheduled, with four flow intervals: 20, 40, 60, 80 L/s, with a duration of 2 hours per interval. For a total duration of 8 hours. Then, on the following day, a continuous pump test of a 24-hour duration with the maximum pump flow (80.4 L/s).

In the JICA 3 well, two pumping tests were carried out, as the well wanted to be tried out at two depths of up to 50 m and up to 80 m. There are no shutters in Cuba to isolate the horizons, so the objective of calculating the parameters by intervals was not met. However, in the JICA 3 well, a test was performed with a depth of 50 m, then the drilling continued until 80 m and a second test was performed installing the pump at a depth of 74 m.

The following table shows the results of the pumping test:

Table 2-3: Table with data from the pumping tests of JICA wells

Well	Date	Q (L/s)	S.W.L (m)	D.W.L (m)	Drawdown
JICA 2	21/02/2015	80.4	9.8	11.44	1.64
Observation Well (Distance 13 m)			9.72	10.45	0.73
JICA 3	30/01/2015	80.4	33.08	33.57	0.49
Observation Well (Distance 30 m)			33.29	33.68	0.39
JICA 3 (2nd Test)	28/08/2015	80.4	33.65	34.21	0.56
Observation Well (Distance 30 m)			33.79	34.23	0.44

The following is a summary of the determination of the aquifer parameters in the JICA wells calculated by the Jacob Methods for pumping and observation wells in the pumping and recovery stages for the wells JICA 2 and 3.

Table 2-4: Summary of the determination of the Hydrogeological Parameters of the aquifer in wells

Calculation method	Well and Stage	T (m^2/d)	S
JICA 2			
Jacob Method	JICA 2 (Pumping Stage)	4257	0.35
	Recovery Stage	4945	-
	Observation Well (Pumping Stage)	4752	2.11E-02
	Recovery Stage	4688	-
Theis Method	JICA 2 (Pumping Stage)	5528	1.71E-02
	Observation Well (Pumping Stage)	7877	3.39E-03
Logan's approximation formula	JICA 2 (stepped pumping)	17089	-
JICA 3 First Test (50m)			
Jacob Method	JICA 3 (Pumping Stage)	8645	2.06E02
	Recovery Stage	25974	-
	Observation Well (Pumping Stage)	8645	3.44E-01
	Recovery Stage	23219	-
Theis Method	JICA 3 (Pumping Stage)	6032	5.08E02
	Observation Well (Pumping Stage)	6718	1.66E-01
Logan's approximation formula	JICA 3 (stepped pumping)	32796	-
JICA 3 Second Test (80m)			
Jacob Method	JICA 3 (Pumping Stage)	4918	1.20E03
	Recovery Stage	10979	-
	Observation Well (Pumping Stage)	4630	1,34E00
	Recovery Stage	8764	-
Theis Method	JICA 3 (Pumping Stage)	6582	5.51E02
	Observation Well (Pumping Stage)	6187	1,26E00
Logan's approximation formula	JICA 3 (stepped pumping)	32105	-

e. Groundwater

Taking into account the particularities of the groundwater regime in the Neogene aquifer complex, it is possible to divide it into two main areas. A first area that extends to the North, from the dividing line of the underground runoff to the hydrohypse +5.

In this part, the oscillations of the levels vary in a hydrological cycle of 2 to 5 m, where the spot heights of the groundwater levels are of 5 to 100 m and the flow gradients of 0.002 to 0.006 and, in the pre-mountain area, of 0.04.

The second area extends to the South from the +5 hydrohypse to the boundary with the saltwater, forming an approximately semi-circular hydrogeological structure limited by faults.

The amplitude of the levels in this area is not greater than 1 m in a hydrological cycle and only when heavy rainfall occurs can reach a maximum of 4 m.

The flow in this area is practically flat, and the minimum gradients reached values below 0.0001.

The underground flow generally runs towards the sea, but in the area of the Cuenca Sur Aqueduct, due to its influence, the flow runs towards the Northwest-Southeast.

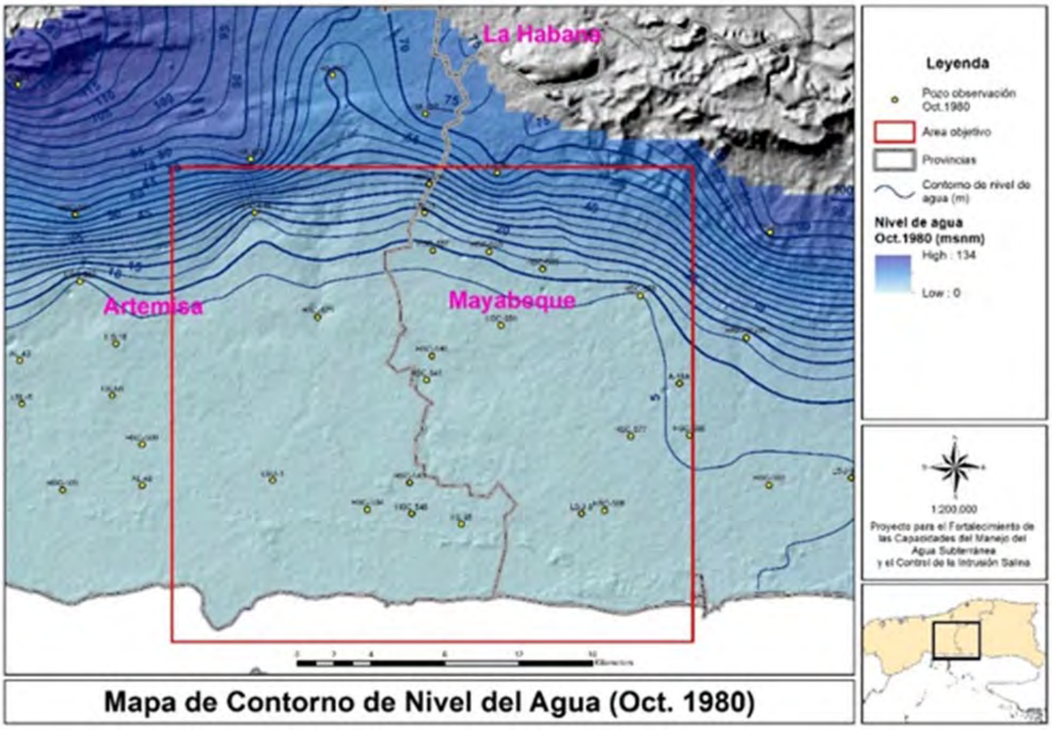

Figure 2-35: Groundwater level contour map (Oct. 1980)

2.3 Groundwater Use

a. Introduction

From the social and economic point of view, the study area is part of one of the most important agricultural areas of the Western region of Cuba, mainly for the food supply of the province and the capital of the country. All offices of the Ministry of Agriculture (MINAGRI by its Spanish acronym) located in the area are responsible for the sowing of assorted crops. Besides, the area has one of the aqueducts with the highest coverage of drinking water for the population of the city of Havana.

Due to the coastal relief and the lack of a hydrographic network, the use of surface water is practically zero, turning the aquifer into the main source of water for the development of the area.

In the study area of the Project there are a total of 143 water users from different OACES (Central Government Agencies) becoming key players for the implementation of the Management Plan.

Table 2-5: Water users of the study area

OACE	OSDE	No	USER	MUNICIPALITY
AZCUBA	Grupo Emp. Azcuba	1	CPA 17 de Mayo	Quivicán
		2	CPA 26 de Julio	Quivicán
		3	CPA Romárico Cordero	Quivicán
		4	UBPC Manuel Fajardo	Quivicán
		5	UBPC Pablo Noriega	Quivicán
		6	UEB Atención a Productores M.Fajardo	Quivicán
		7	UBPC J Gaspar G Gallo M.Fajardo	Quivicán
		8	UEB Central Azucarero Manuel Fajardo	Quivicán
		9	Cuba 9	Quivicán
	ICIDCA	10	ETICA	Quivicán
INRH	GEAAL. Mayabeque	11	Buenaventura	Bejucal
		12	Cuatro Caminos	Bejucal
		13	Aguacate	Quivicán
		14	Güiro Boñigal	Quivicán
		15	Güiro Marrero	Quivicán
		16	Paradero	Quivicán
		17	Santo Cristo	Quivicán
		18	Mi Retiro	Quivicán
		19	Yolando Glez 1	Quivicán
		20	Camacho	Batabanó
		21	Pedroso	Batabanó
		22	Pozo Redondo	Batabanó
	Aguas de la Habana	23	K21W1 (1)	Quivicán
		24	K21W2 (2)	Quivicán
		25	K22E1 (3)	Quivicán
		26	K23E1 (4)	Quivicán
		27	K23E2 (5)	Quivicán
		28	G1 (6)	Quivicán
		29	G2 (7)	Quivicán
		30	G3 (8)	Guira
		31	K24W1 (9)	Quivicán
		32	K24W2 (10)	Quivicán
		33	K24W3 (11)	Quivicán
		34	K26W1 (12)	Quivicán
		35	K26W3 (13)	Quivicán
		36	K26W4,5 (14)	Quivicán
		37	K26W6 (15)	Guira
		38	K26W7 (16)	Guira
		39	K26E2 (17)	Quivicán
		40	K26E4 (18)	Quivicán
		41	K26E5 (19)	Quivicán
	GEAAL Artemisa	42	El Valle	San Antonio de los Baños
		43	La Encrucijada	San Antonio de los Baños
		44	Campamento	San Antonio de los Baños
		45	Mi Rancho	San Antonio de los Baños
		46	Amparo	Alquizar
		47	Bejerano	Alquizar
		48	Guanimar	Alquizar
		49	La Europa	Alquizar
		50	Las 400	Alquizar
		51	Mayorquín	Alquizar
		52	Pulido	Alquizar
		53	Cajio	Guira de Melena

		54	El Gabriel	Guira de Melena
		55	Guira Nuevo	Guira de Melena
		56	Guira Viejo 1	Guira de Melena
		57	Guira Viejo 2	Guira de Melena
		58	La Cachimba	Guira de Melena
		59	Zona de Desarrollo	Guira de Melena
MINAGRI	EA 19 de Abril	60	EA 19 de Abril	Quivicán
		61	CCS 2da Declaración	Quivicán
		62	CCS 30 de Noviembre	Quivicán
		63	CCS Antonio Guiteras	Quivicán
		64	CCS Camilo Cienfuegos	Quivicán
		65	CCS Abel Santa Maria	Quivicán
		66	CCS Cuba Socialista	Quivicán
		67	CCS EduardoGarcía	Quivicán
		68	CCS Fructuoso Rguez	Quivicán
		69	CCS José A. Echeverría	Quivicán
		70	CCS José Luis Tasende	Quivicán
		71	CCS Juan M Marquez	Quivicán
		72	CCS Julio Trigo	Quivicán
		73	CCS Manuel Ascunse	Quivicán
		74	CCS Martires de Barbados	Quivicán
		75	CCS Nicomedes Corvo	Quivicán
		76	CCS Van Troy	Quivicán
		77	CPA Pedro Lantigua	Quivicán
		78	CPA Pedro Rguez Santana	Quivicán
		79	Granja Urbana	Quivicán
		80	IPA Fructuoso Rodriguez	Quivicán
		81	UBPC Manuel Isla	Quivicán
		82	UBPC William Soler	Quivicán
	EA Guira de Melena	83	UPR Vavilot	Guira de Melena
		84	ACTAF Provincial Guira	Guira de Melena
		85	EA Guira Servicios Técnicos	Guira de Melena
		86	EA Guira Granja Urbana	Guira de Melena
		87	Autoconsumo ANAP	Guira de Melena
		88	CCS 1ero de Mayo	Guira de Melena
		89	CCS Camilo Cienfuegos	Guira de Melena
		90	CCS Frank País	Guira de Melena
		91	CCS Niceto Pérez	Guira de Melena
		92	CCS Antero Regalado	Guira de Melena
		93	CCS Nguyen Van Troy	Guira de Melena
		94	CCS Raul Cepero Bonilla	Guira de Melena
		95	CCS Viet Nam Heróico	Guira de Melena
		96	CCS Ubaldo Díaz Fuente	Guira de Melena
		97	CPA Amistad Cuba Países Nórdicos	Guira de Melena
		98	CPA Niceto Pérez	Guira de Melena
		99	CPA Ubaldo Díaz Fuente	Guira de Melena
		100	UBPC Héroes de Bolivia	Guira de Melena
		101	UBPC Héroes de Yaguajay	Guira de Melena
	EA Alquizar	102	UCTV Experimental de campo	Alquizar
		103	UEB Plantas Medicinales	Alquizar
	Centros de Investigación	104	IIH Liliana Dimitrova	Quivicán
	TABACUBA	105	Resecadora de Tabaco	Quivicán
	Empresa Avícola Quivicán	106	Granja Avícola La Soria	Quivicán
		107	Granja Avícola La Mariana	Quivicán
		108	Granja Avícola San Agustín	Quivicán

		109	Granja Avícola Tamaulipa	Quivicán
		110	Granja Avícola Victoria de Girón	Quivicán
		111	Granja Avícola LPV	Quivicán
		112	Gja Avícola Pedroso	Batabanó
	Emp. Porcino Habana	113	Porcino Quivican	Quivicán
		114	Porcino Los Baez	Quivicán
	EA Batabanó	115	CCS Juan B. Ruiz	Batabanó
		116	CCS Santiago Castañeda	Batabanó
		117	UBPC Ruben Marichal (Bat)	Batabanó
MINAL	Emp. Doña Delicias	118	Emp Conservas Caribe(Quivican)	Quivicán
	Emp. Bebidas y Licores	119	Fábrica de Ron	Guira de Melena
MINCIN	Comecio Interior	120	Establecimiento 202 Frigorífico Abel Sta María	Guira de Melena
MINFAR	EAMilitar Oeste	121	GMI 17 de Abril	Quivicán
		122	GMI La Magela	Quivicán
		123	GMI Camacho	Batabanó
	EAMilitar Oeste	124	GMI Los Moros	Guira de Melena
		125	GMI Barnet	Guira de Melena
		126	GMI Sonrisa de la Victoria	Guira de Melena
MININT	Emp. CH-1	127	Granja Integral Quivican	Quivicán
		128	Granja El Laurel	Quivicán
		129	Gja Unión Quiv	Quivicán
		130	Granja Camilo Cienfuegos	Quivicán
		131	Granja Baragúa	Quivicán
		132	Granja El Cafetal	Quivicán
	Centro de Prisiones	133	PROVARI Quivicán	Quivicán
		134	Penal Quivican	Quivicán
		135	Campamento Inocencio	Batabanó
	Emp. Agrop Industrial El Coral	136	Finca Corralillo	Alquizar
		137	Finca La Celita	Alquizar
		138	Finca La Esperanza	Alquizar
		139	Finca Novedades	Alquizar
MINENM	Empresa Eléctrica	140	UEB Generación Este Quivicán	Quivicán
MINED	MINED	141	Escuela Nac. de Cuadros de la ANAP	Guira de Melena
		142	UAC Educación y Cultura	Guira de Melena
MES	MES	143	Instituto Superior Rubén M. Villena	Alquizar

Table 2-6: Summary of water users by organizations

ORGANIZATION	USERS Mayabeque	USERS Artemisa	JICA PROJECT AREA	SERVICE or PRODUCTION
INRH	31	18	49	Aqueduct for the human supply
AZCUBA	10	0	10	Sugar and honey
MINAGRI	37	21	58	Tubers, grains, vegetables and others
MINAL	1	1	2	Canned fruits, vegetables and liquors
MINFAR	3	3	6	Tubers and grains
MININT	9	4	13	Tubers, grains and other supplies
MINEM	1	0	1	Power generation
MINED	0	2	2	Education
MINCIN	0	1	1	Home trade
MES	0	1	1	Higher Education
TOTAL	92	51	143	

A total of 711 exploration wells linked to the groundwater exploitation were inventoried for the economic and social development in the area including the wells supporting the Pedroso-Güira channel.

Table 2-7: Census of exploitation wells in the study area

No	ACTIVITY	Organization	Subordination	Owner	Coordinate		Diameter inches or m	Use (l/s)	Daily exploitation hours
					x	y			
1	AGRICULTURA	MINAG	CCS 2da Declaración (Quivican)	Esteban Hernández	356187	330470	0.53	20	8
2				Roberto Hernández	352360	333960	0.53	18	8
3				Antonio Díaz	357140	334050	0.53	18	6
4				Silvestre Acosta	357057	332597	0.41	20	10
5				Felix Acosta	360189	330408	0.41	30	10
6				Nivaldo Hernández	355386	330794	0.41	30	8
7				Simón González	356397	331714	0.41	18	6
8				Epifanio Mesa	357308	332826	0.41	18	6
9				Alejandro Sanchez	354514	331849	0.41	18	8
10				Juan Valdéz	355932	331981	0.41	18	8
11				Felicia C. Hernández	355703	330728	0.41	18	6
12				Gregorio González	355550	330844	0.41	18	6
13				Juan J. Hernández	354057	331491	0.41	18	6
14				Antonio García	356567	332625	0.41	18	6
15				Orlando Alfonso	353919	331450	0.41	18	6
16				Lázaro Acosta	355415	331636	0.41	18	8
17				Eraclio Mesa	355656	332063	0.41	18	6
18				Guillermo Alonso	354550	330670	0.53	18	12
19				Juan C. Lemus	356096	331224	0.53	18	8
20				Zoe Rivero	356614	332641	0.53	20	12
21				Urbano Rodríguez	354802	334444	0.41	18	8
22				Agustín Hernández	355560	330930	0.41	18	6
23				Humberto Matrínez	356325	330791	0.41	18	6
24				Servilio Soca	353473	330445	0.41	18	12
25				Pedro Ileso	356969	331529	0.46	18	6
26				Nicasio Rodríguez	356410	330228	0.46	20	6
27				Jesúa R. Mozegui	354196	335726	0.46	20	12
28				Ramón Espinosa	356068	331504	0.41	30	10
29				Carlos Malagón	355499	331243	0.41	18	6
30				Tierra Colectiva	355417	330492	0.41	20	12
31				Raul Reyes	355414	336988	0.41	18	10
32				Francisco Barreto	355917	330533	0.41	20	6
33				Elsa M. Cruz	355207	329676	0.53	18	6
34				Domingo Roque	355741	330825	0.41	18	8
35			CCS Nicomedes Corvo (Quivicán)	Jesus Fortes	360260	334240	0.50	60	8
36				Jesus Fortes	359970	333840	0.50	60	6
37				Jesus Fortes	359550	334400	0.40	30	7
38				Eligio Fortes	360180	334540	0.50	65	12
39				Bernardo Diaz	357820	335260	0.50	45	10
40				Bernardo Diaz	358030	336200	0.50	65	8
41				Sixto Rodriguez	359800	333250	0.50	75	12
42				Francisco Beltran	360060	333180	0.40	25	10
43				Miguel A Corvo	359820	334200	0.40	45	12
44				Benito Fortes	359900	334200	0.50	80	10
45				Isidro Hernandez	359480	334720	0.30	45	12
46				Isrrael Bobey	359900	336480	0.40	65	8
47				Josefa Rivero	359480	337980	0.40	15	8

48				Isrrael Dominguez	358730	338900	0.50	45	12
49				Gilberto Martinez	358200	339700	0.50	45	8
50				Armando Rodriguez	356900	339350	0.40	25	12
51				Adelfa Ravelo	357200	339520	0.40	12	12
52				Eladio Rabelo	358780	337540	0.40	15	10
53				Jesus Perez	360100	336780	0.40	30	10
54				Matias Martinez	357040	336250	0.50	30	12
55				Roberto Reyes	350510	337100	0.50	45	8
56				Enma Coypell	358240	332680	0.50	65	8
57				Pedro A. Beltrán	358710	333340	0.50	75	6
58				Pedro A. Beltrán	358780	332220	0.50	75	8
59				Pedro A. Beltrán	357500	332220	0.25	20	1
60				Jesús Gonzalez Martínez	359080	333980	0.40	30	4
61			CCS EduardoGarcía (Quivican)	Diego Martínez	354650	341300	0.5	10	3
62				Iliana F. Hernández	351800	342000	0.5	12	2
63				Félix J. Hernández	354025	341800	0.4	12	3
64				Antonio Viera	353700	341850	0.4	12	3
65				Francisco Maristán	353850	341325	0.5	12	3
66				José Rosendo Hernández	354025	340175	0.4	12	2
67				Domingo O. Dominguez	353675	341175	0.4	12	2
68				Pedro Linares	354250	341600	0.5	12	4
69				Raúl Morejón	356080	340715	0.5	12	4
70				Romelio B. Rodríguez	353500	341400	0.5	12	4
71				Manuela Martínez	352350	341550	0.5	12	4
72				Segundo G. Chavez 1	355150	338560	0.4	20	4
73				Segundo G. Chavez 2	356125	338250	0.5	45	6
74				Segundo G. Chavez 3	355820	338125	0.5	45	6
75				Roberto León	355000	342125	0.3	20	4
76				Reynaldo Valiente	354800	342820	0.3	15	2
77				Eladia Capote	353600	342175	0.3	12	2,5
78				Odalis Cabrera	353200	341425	0.3	10	3
79				Braulio Cartaya	352925	341500	0.4	15	3,5
80				Ramón González	353750	341850	0.3	12	2
81				Timoteo J. García	352350	342000	0.3	12	2,5
82				Simón E. Domínguez	354200	340650	0.3	15	3
83				Servilio Estévez	355410	341900	0.3	12	3,5
84			CCS Fructuoso Rguez (Quivicán)	Máximo Sixto Pérez	355295	338000	0.6	27	8
85				Máximo Sixto Pérez	355575	338150	0.5	27	8
86				Lázaro Alonso	363650	332275	0.4	22	3
87				Rigoberto Cámara	365000	330450	0.4	22	3
88				Fidel Rodríguez	364250	332700	0.6	28	5
89				Eugenio C. Díaz	366900	332000	0.4	18	5
90				Policarpo Rodríguez	366860	332275	0.4	18	2
91				Oscar Díaz	366250	331125	0.4	27	6
92				Pascual González	366340	333525	0.4	18	5
93			CCS José A. Echeverría (Quivicán)	Severino Medina 1	354360	329200	4"	18	2
94				Severino Medina 2	354330	329340	8"	55	4
95				Carmelina Socas	353780	329725	4"	20	5
96				Ramó Llanes	353425	328630	3"	15	2
97				Aurelio Cruz	353275	330575	6"	30	5
98				Sergio Amable	352680	330575	4"	20	3
99				Antonio Morales	352330	330352	6"	40	4
100				Serafín Morales	352490	330425	6"	40	4

101				Severino Beceiro	351575	330525	6"	30	3
102				Guillermo Espinosa	354175	330300	4"	18	2
103				Eriberto Mederos	349900	330350	8"	55	6
104				Dora Rabelo	349550	330400	4"	20	2
105				Juan Hernández	349975	331000	8"	75	5
106				Miguel Díaz	351650	330700	3"	15	5
107				Dario Triana 1	351600	331450	8"	60	5
108				Dario Triana 2	351080	331030	6"	30	5
109				Eduardo Acosta	351130	332125	4"	20	7
110				José Rabelo	351225	332000	6"	40	4
111				Justo Maristán 1	352060	332840	6"	45	5
112				Justo Maristán 2	351840	332880	6"	30	4
113				Homero Rodríguez	351840	333100	4"	20	3
114				Rogelio González	352290	331250	4"	20	7
115				Ricardo Castillo	352670	333075	4"	20	7
116				Oralndo González	352275	333130	4"	20	6
117				Roberto González	352400	333980	6"	35	6
118				María F. Reyes	351200	333975	4"	20	6
119				Tania M. Avila	350480	337025	4"	20	4
120				Gonzalo Rodríguez	350100	336500	4"	20	6
121				Alberto Maristán	349450	335250	6"	45	4
122				Israel Domínguez 1	354975	336975	6"	45	5
123				Israel Domínguez 2	355700	336780	6"	35	3
124				Manuel Espinosa	354220	330325	8"	50	4
125				Uso Colectivo	352050	334100	4"	20	4
126				Israel González	355980	336200	8"	30	4
127			CCS José Luis Tasende (Quivicán)	Pedro Alonso	360375	336910	0.4	20	3
128				Avelino Díaz	361175	336375	0.4	20	1
129				Petrona Delia	362675	336550	0.5	18	2
130				Vicente Viera	361300	336000	0.5	38	3
131				Rolando Cuellar	362500	336300	0.4	18	4
132				Enrique Lorenzo	365810	337080	0.4	18	4
133				José Hernández	366080	335700	0.4	19	2
134				Angel Candelario	365500	336860	0.4	18	2
135				Rolando Díaz	365900	336090	0.2	10	3
136				Lázaro Claro	364775	337525	0.4	20	3
137				José M. Llanes	363030	334685	0.4	20	3
138				Marcial Díaz	361125	336450	0.4	20	1
139				Luis Viera	362625	336550	0.4	20	5
140				Robeto Álvarez	362135	336075	0.4	20	1
141				Obdulio Martínez	364585	337250	0.3	17	5
142				Lázaro Santos	364750	335825	0.3	18	1
143				Roberto Rodríguez	361170	333074	0.2	10	4
144			CCS Juan M Marquez (Quivican)	Nelson González	360175	331000	0.2	30	12
145				Evaristo Acosta	360130	330400	0.2	20	16
146				Ana M. Campos 1	360365	332735	0.2	45	6
147				Ana M. Campos 2	360425	332800	0.2	45	10
148				José L. Pedroso	360780	332375	0.2	45	16
149				Angelito Llanes	361000	331300	0.5	45	16
150				Caridad Ramos	360575	331400	0.2	30	7
151				Fernando Arroyo	361250	331380	0.2	30	4
152				Nancy Robira	362100	329400	0.16	20	12
153				Alfredo Franco 1	362510	328325	0.18	10	4
154				Alfredo Franco 2	362325	328250	0.18	10	10
155				Alfredo Franco 3	362525	327460	0.16	35	8

156				José M. Blanco	362000	327750	artesiano	28	16
157				Juan M. Pérez	360395	331190	0.2	60	6
158			CCS Camilo Cienfuegos (Quivicán)	Nicasio L. Martínez	356750	330075	0.5	20	4
159				Romelio Martínez 1	339060	330600	0.5	20	2
160				Romelio Martínez 2	359610	330630	0.5	20	4
161				Osvaldo González	357200	330300	0.4	18	3
162				Juan Padrón	356900	330100	0.5	20	5
163				Efraín Rspinosa	357980	330400	0.4	18	4
164				Eduardo Viera	358800	331025	0.5	20	4
165				Miguel González	359125	330780	0.5	20	4
166				Porfirio Llanes	357195	331100	0.5	25	6
167				Felipe Cruz	356350	330250	0.5	20	6
168				Rodrigo Méndez	357250	328650	0.5	20	3
169				Humberto Acosta	358075	329175	0.3	18	3
170				Loida Castro	359175	329150	0.5	20	2
171				Roberto Hernández	359125	329250	0.4	18	2
172			CCS Martires de Barbados (Quivicán)	Carmen Marquez Rivero	360025	336500	0.4	15	6
173				Abilio Martínez	357700	339100	0.4	20	4
174				Severo Rodríguez	357565	339380	0.4	20	4
175				Edelvis González Nuňez	357365	339400	0.5	40	5
176				José M. Gutierrez	358140	339575	0.5	30	8
177				Zaida Viera Alonso	358825	339995	0.4	20	6
178				Orlando Martínez Jorge	358210	339650	0.4	40	4
179				Armando Rodríguez	356970	339400	0.4	20	4
180				Paula A. Rabelo	357225	339475	0.4	12	5
181				Lázara Rabelo	358775	337525	0.4	15	6
182				Jesús Pérez Pérez	360050	336400	0.4	30	6
183				Pedro Sánchez Pérez	359700	336555	0.4	30	5
184				Matías Martínez Hernández	359075	336000	0.4	30	8
185				Pedro R. Martínez	357495	336698	0.5	60	6
186				Francisco M. Martínez	359900	336360	0.3	20	8
187				Jorge Romero Medina	358165	338025	0.5	50	4
188				Arnaldo Z. Valladares	357800	336365	0.4	20	3
189				José S. Alonso	359725	336950	0.4	20	6
190				Jesús Colón Sánchez	359500	336570	0.4	20	6
191				Rosalina López	359675	336900	0.4	20	6
192				Luis Delgado Ribot	359675	336990	0.4	20	6
193				Israel Domínguez	358700	338825	0.4	20	4
194				Francisco Hernández	359650	336755	0.4	18	5
195				Raíl A. Cuellar	361440	336500	0.4	18	5
196				Silvestre Cabezas	357725	338700	0.4	18	4
197				Vladidmir Hernández	358468	338215	0.5	30	9
198				Humberto Fonseca	362660	333750	0.4	20	6
199				Reynaldo Escobar	356125	339180	0.5	30	6
200			CPA Pedro Rodríguez Santana	CPA Pedro Rodríguez San 1	351590	331840	6”	30	8
201				CPA Pedro Rodríguez San 2	351920	331780	6”	45	8
202			CCS Juan B. Ruiz (Batabano)	Juan Emilio	365250	325575	4"	20	8
203				Aurelio González	365250	324250	6"	45	8
204				Lázaro Delgado	365780	324915	3"	10	8
205				Leonel Báez	366025	325650	6"	45	7
206				Alejandro González	365225	328925	4"	25	8

207				Miguel Martínez	365750	327475	3"	10	8
208				Leoncio Barrios	366855	327220	4"	25	8
209				Fernando Lugo 1	367775	326180	4"	25	8
210				Fernando Lugo 2	367525	326375	4"	20	6
211				Francisco Navarro	366475	326200	6"	36	6
212				José Delgado	363510	324250	6"	45	7
213				Gustavo Pérez	364850	327250	6"	30	8
214				Finca Colectiva	366225	326260	4"	29	8
215				Cirilo González	365240	325575	4"	20	8
216				José Baez	365875	325625	4"	26	8
217				Jesús Díaz	363455	326460	6"	40	8
218				Benancio Lozada	367350	324450	4"	20	7
219				Isidro Marquez	365700	326750	4"	20	7
220				Michel Cantero	367075	324350	4"	20	7
221				Odalia Lozada	367000	324560	4"	20	8
222				Ramón Cruz	365910	327035	4"	20	6
223				Eladio Sánchez	365100	325225	4"	20	8
224				Ramón Duran	365100	325130	4"	10	8
225				Leosvany Losada	366860	324560	4"	20	6
226				Joaquín Valdéz	366130	325250	4"	20	6
227				Felix Hernández 1	366600	324357	4"	20	8
228				Felix Hernández 2	366775	324950	4"	20	8
229				Fernando Sánchez	364975	326600	4"	20	8
230				Julián González	365325	326725	6"	30	8
231				Luis Salgado	366450	324560	4"	20	6
232				Manuel Espinosa	363550	326250	4"	20	8
233				Pedro Llanes	365525	325950	4"	20	8
234			CCS Deris Gracía (Bat)	Agustin	368000	323410	4"	20	8
235				Frank Dias	367215	323100	6"	45	8
236				José Lago	367483	322845	6"	30	8
237				CCS	367862	323754	6"	45	8
238				Ruperte Avila	367258	322065	6"	45	8
239				Nesto Granado	366030	323830	10"	160	8
240				Evelio Dias	367495	322120	10"	160	8
241				Norberto Saabedra	366250	325380	6"	45	8
242				Pablo Guerra	366295	323580	8"	75	8
243				Felix Nuñes	367750	322050	8"	75	8
244				Daniel Roz	367200	323620	8"	75	8
245				Raul Dias	368290	322260	6"	45	8
246				Rogelio Hdez	367250	323261	6"	45	8
247				Gerardo Caraballo	368500	323000	6"	30	8
248				Gilberto Caraballo	368800	322450	6"	30	8
249				Roberto Alfonso	368920	322010	6"	45	8
250				Arcenio Alfonso	368020	322110	4"	20	8
251				Ramón Caraballo	369250	323080	4"	20	8
252				David Montero	369750	322190	10"	100	8
253				Cheito	363250	324850	6"	45	8
254				Los Medinas	366750	324725	8"	75	8
255			CCS Eduardo Elfonso (Bat)	Eladio Dias	366350	329789	6"	30	8
256			CCS 9 de Abril (Bat)	1	367100	327200	6"	45	8
257				2	366595	326820	6"	30	8
258				3	369200	328450	6"	30	8
259				4	367590	331850	6"	45	8
260			CCS Niceto Pérez (Bat)	Fc Colectiva	367566	323850	4"	20	8
261				Eddy Medero	368025	323345	4"	20	8

262				Leonardo D	366860	323265	8"	75	6
263			CCS Rubén Marichal (Bat)	Yoel martines	360204	326110	6"	45	6
264				Tonito	361252	322151	8"	75	6
265				Tomas	360310	322450	8"	75	6
266				Jorge Felix	361500	322150	8"	75	6
267				Alexander	361910	322150	8"	75	6
268				Alfredo	359950	322150	4"	20	6
269				Miguel	360452	323520	4"	18	6
270				Ernesto	360090	323680	8"	75	6
271			CCS Pablo Noriega (Bat)	Elier Valdez	367500	328150	6"	45	10
272				Rolando V	366810	328700	4"	20	8
273				Los Isleños	368150	329300	6"	50	4
274				Los Cabezas	368160	329500	8"	60	6
275				Alberto Garcia	366710	329900	6"	30	8
276				Ismael Delgado	367850	329560	4"	18	8
277				Fca Colectiva	367450	329600	4"	10	8
278				Agustin Alfonso	368195	330050	6"	45	8
279			CPA 9 de Abril (Bat)	Dionicia	367900	320850	6"	45	8
280				Chita Maceo	366750	320200	4"	20	8
281				Fca Colectiva	365950	321020	4"	18	8
282			CPA Alianza Obrero Campesina (Bat)	Huerto	366803	321820	6"	45	8
283				Pereda	368600	323620	8"	75	8
284				Mameyal	367010	322250	8"	75	8
285				La Bertica	366395	323690	6"	45	8
286				La Vaqueria	365980	322560	6"	30	8
287				Huerto Grande	366795	322150	8"	60	8
288			CPA Manuel Ascunce (Bat)	Peralta	366850	320890	10"	100	8
289				Pescoson	366490	320900	6"	45	8
290				Berro 2	367300	320415	8"	75	6
291			Granja Urbana Batabanó (Bat)	Anofre	366010	321450	4"	20	6
292				Alberto Dias	368820	328490	6"	30	6
293				EB 32	367210	328680	4"	20	6
294				Arroz	368786	324650	3"	10	6
295				14	369990	330750	6"	45	6
296				35	368150	326650	6"	45	6
297				37	368510	326500	6"	50	6
298			Gja Avícola Pedroso (Batabano)	Gja Avic. Pedroso	364970	323530	0.2	10	3
299			UBPC Ruben Marichal (Bat)	El Quintero	366750	321980	0.6	45	8
300				Pedroso	365590	321640	0.6	50	8
301			CCS 1ero de Mayo (Guira de Melena)	Loredo	343534	328538	6"	45	8
302				Eugenia Margarita Zaldivar	343506	328386	6"	45	8
303				David Suarez Ramos	343042	329544	6"	50	10
304				MarÍa E. Ceciia Otero	344641	329003	8"	60	16
305			CCS Raúl Cepero Bonilla (Guira de Melena)	Secundo González Chirino	344997	327697	6"	45	8
306				Secundo González Chirino	344950	327612	6"	45	8
307				Secundo González Chirino	344830	327367	8"	75	16
308				Orlando Ruisanchez Felipe	344534	327813	8"	75	8
309				Orlando Ruisanchez Felipe	344226	327831	10"	220	16
310				Bernardo	344005	327999	6"	45	10

311				Maximino González	343962	329102	4"	20	6
312				Maximino González	343782	329163	6"	45	10
313				Paula M González	343200	328836	6"	30	10
314				Lourdes Días García	343217	329005	6"	45	24
315				Pedro	343137	328997	6"	45	9
316				Arnaldo Pino Rosquete	342922	328812	10"	160	8
317				Lázaro Pino acosta	342759	329229	10"	160	18
318				Arnaldo Pino Rosquete	344734	327184	6"	45	8
319				Juana E Capote	345048	327250	8"	75	8
320			CCS Camilo Cienfuegos (Guira de Melena)	Severo Sánchez Días	342997	327788	8"	150	8
321				Héctor Carvajal	343142	327507	8"	75	10
322				Andrés Carvajal	343321	327921	6"	45	8
323				Miguel Carvajal	343247	327942	6"	60	8
324				Jorge L González Domínguez	343065	327984	6"	45	8
325				alejandrina Domínguez	343093	328191	6"	60	8
326				Juan M Jorge García	343224	328144		25	4
327				Milagros Montesinos	345229	329285	8"	75	8
328				Pedro Luís González	343133	328483	8"	220	8
329				Pedro Luís González	342688	328553	8"	75	8
330				Pedro Luis González	342660	328545	8"	75	10
331				Octavio Domínguez	342631	328416	8"	75	9
332				Tranquilino Echevarría	342522	328863	8"	75	8
333				Merandi Capote	342363	328164	8"	60	8
334				Merandi Capote	342473	328300	8"	75	10
335				Amado r Domínguez Estévez	342750	328246	8"	60	8
336				Juan Musibay Lemus	342091	328084	8"	75	10
337				Pedro Rosquete Domínguez	342393	327745	10"	200	8
338				Pedro Rosquete Domínguez	342395	327738	6"	60	8
339				Pedro Rosquete Domínguez	342667	327820	6"	45	8
340				Pedro A Ortega	341998	327397	8"	75	8
341				Pedro A Ortega	342093	327516	8"	75	8
342				Ismael Rop	342200	328356	8"	75	10
343			CCS Frank País (Guira de Melena)	Primo F. Martínez Martinez	346456	323004	6"	45	10
344				Primo F. Martínez Martinez	346456	323004	6"	30	8
345				Primo F. Martínez Martínez	346340	323024	6"	45	8
346				Francisco J. Rodríguez Galindo	346718	323957	10"	120	8
347				José M.Márquez Trujillo	347429	323261	6"	40	8
348				Frank Leal González	348060	322846	6"	45	8
349				Finca Colectiva	348398	322818	6"	60	8
350				Juan G.Ortega	348968	322758		25	8
351				Miguel Díaz Piedra	348862	322482	8"	75	8
352				Miguel Díaz Piedra	348849	322348	6"	30	8
353				Carlos Piedra González	352778	322302	6"	30	8
354				Fermín Piedra González	352616	322328	6"	30	8
355				Neyda Tabares Díaz	352585	322125	6"	45	8

356				Neyda Tabares Díaz	352734	322103	6"	45	8
357				Antonio N. Cordoba Sicle	352557	321972	8"	60	8
358				Juan Argelio Tabares Díaz	352353	322388	8"	75	8
359				Juan Argelio Tabares Díaz	351947	322204	6"	45	8
360				Juan Argelio Tabares Díaz	351820	322038	6"	60	8
361				Nelson Cordoba	351752	322457	6"	45	8
362				Silvino Muñoz González	351637	322177	6"	45	8
363				Juan Ramón Tabares Díaz	351830	322373	6"	45	8
364				Rafaela Matos Ordeñez	351527	322464	6"	30	8
365				Arturo Fernández Viera	351373	322479	6"	30	8
366				Arturo Fernández Viera	351172	322504	6"	60	8
367				Encarnación Muñoz	351289	322067	6"	45	8
368				Encarnación Muñoz	351205	322101	6"	45	8
369				Fernando Leal Hernández	350843	322507	6"	60	8
370				Frank Leal González	350728	322103	6"	45	8
371				Frank Leal González	350860	322074	6"	45	8
372				Rubén Pérez Leyva	350739	322490	6"	40	8
373				Víctor R. Cabrera González	350653	322560	8"	60	8
374				Víctor R. Cabrera González	350543	322437		40	8
375				Jorge Luis Yumat Rodríguez	350413	322579		40	8
376				Raudel Pérez Ravelo	350271	322379		27	8
377				Ramón A. Muñoz Álvarez	350354	322205		40	8
378				Raudel Pérez Ravelo	350023	322576		27	8
379				Raudel Pérez Ravelo	350091	322365		60	8
380				Pablo Daniel Arias Gutiérrez	349945	322612		30	8
381				Feliberto Leal Rodríguez	349762	322600		45	8
382				Eustasio Pedraza Pedraza	349434	322679		27	8
383				Juan Julio González Trujillo	349349	322713		45	8
384			CCS Niceto Pérez (Guira de Melena)	Agustin N. Piedra Piedra	346642	322988		45	8
385				Agustin Noel Piedra Piedra	346508	323004		60	10
386				Eduardo Edel Yero Agüero	345986	323056		40	8
387				Daniel Cirilo González Chirino	345996	323256		60	8
388				Manuel Hernández Hernández	347392	323803		75	8
389				Ciro Núñez Hernández	344059	323266		27	8
390				Ciro Núñez Hernández	344449	323222		27	8
391				Wilfredo A. Leal Hernández	345076	323492		45	8
392				Hirán González Barrios	347038	322891		45	8
393				Eurelio Leal Díaz	344448	323496		30	8

394				Eurelio Leal Díaz	344071	323555		30	8
395				Gliser Perez San Juan	344616	323475		75	8
396				Saturnino I. Sánchez Barrio	343844	323091		40	8
397				Lazaro O. González Oliva	343590	323113		30	8
398				Rafael Perez Camacho	343498	323150		45	8
399				Manuel Amaro Quintero	342948	323388		45	8
400				Leonardo Amaro Álvarez	342805	323441		27	5
401				Francisco Álvarez Millo	340049	324598		30	5
402				Raúl Rivera Lores	343934	323683		45	8
403				Pedro Betancourt Rodríguez	347369	322894		45	8
404				Julio Hernández Santos 1	347460	322891		45	8
405				Julio Hernández Santos 2	347555	322878		45	8
406				Solicitada por la 300	347825	322878		30	8
407				Norberto Carbonell	345078	327221	8"	75	8
408				Emilio González	344827	326942	6"	45	18
409			CCS Antero Regalado (Guira de Melena)	Luis Leal Domínguez	342708	330413		50	12
410				Luis Leal Domínguez	342599	330922		45	9
411				Arnaldo Rodríguez Hernández	343660	330622		60	12
412				Bernarda A Saavedra González	344096	330406		40	12
413				Granja Urbana	344162	330548		30	12
414				Justo E Cabarro Martínez	344399	330774		75	12
415				Justo E Cabarro Martínez	344391	330927		75	8
416				Raymundo Leal Rodríguez	343495	330385		75	10
417				Félix Fernández Chávez	343478	330368		75	8
418				Félix Fernández Chávez	343843	329768		45	5
419				Higinio Sánchez Sánchez	343641	329839		45	8
420				Pastor Rodríguez Salgado	343409	329955		75	8
421				Irino Obdulio Leal Carrillo	343410	329952		75	8
422				Irino Obdulio Leal Carrillo	343452	329944		45	5
423				Juan Sánchez	343042	329983		150	9
424				Milagros Barreto	343070	329955		35	10
425				Estrella García Otero	342837	330000		45	11
426				Estrella García Otero	344145	329063		40	7
427				Rolando Martínez Menéndez	346151	330778		75	8
428				Rolando Martínez Menéndez	344355	329148		60	8
429				Rolando Martínez Menéndez	342828	329747		75	12
430				Jorge Suarez Rodríguez	342828	329747		45	8
431				Isaac Felipe Borrego Ramos	342753	329588		45	8
432				Anselmo E Mauri	342697	329402		35	8
433				Yulien Castro Estévez	342611	329421		45	8

434				Felino de la C Chávez González	343589	328768		30	4
435			CCS Nguyen Van Troi (Guira de Melena)	Juan Piedra	355267	321755		30	8
436				Erik Piedra Torres	354864	321892		10	8
437				Félix Pupo Torres	354738	321892		10	8
438				Félix Pupo Torres	354724	321809		25	8
439				Carlos Manuel Leal Piedra	354545	321927		45	8
440				Bárbaro Piedra	354182	321989		45	8
441				José Ramón González Piedra	353973	322027		30	8
442				José Ramón González Piedra	353891	321798		45	8
443				Pedro González Díaz	353484	322151		45	8
444				Tomás Rodríguez Garbes	353341	322075		30	8
445				Baudilio Rodríguez Garbes	353411	322124		15	8
446				Amado Piedra González	353009	321626		27	8
447				Amado Piedra González	353085	321591		30	8
448			CCS Viet Nam Heróico (Guira de Melena)	Bernardo	344633	327035		45	8
449				Jorge Silva Monnos	344338	327418		75	8
450				Jorge Silva Monnos	344065	327629		160	8
451				Carlos Montesinos	344074	327471		75	8
452				Carlos Montesinos	343979	327272		45	8
453				Dionisio J Martínez González	344418	326828		45	8
454				Rosa Tomasa López	344307	327737		45	12
455				José Alberto Soca	344520	326753		45	8
456				Mario Fiandor Galindo	343953	327185		75	8
457				Mario Fiandor Galindo	343833	327247		30	8
458				Julio F Capote	343348	327123		75	8
459				El chino	343471	327669		75	10
460				Osviel Fiandor	343137	327226		75	10
461				Osviel Fiandor	342931	327348		75	8
462			CCS Ubaldo Díaz (Guira de Melena)	El Coco 1	344813	329064		75	8
463				Emilio Alcántara Rodríguez	343964	330815		20	8
464				Raudel Cabaña Rodríguez	343881	330188		20	5
465				Alejandro J Bonego Hernández	343809	330326		60	8
466				Luis Otero Aritola	343501	330382		40	6
467				Armando Rodríguez Lorenzo	343569	330742		75	8
468			CPA Amistad Cuba Paises Nórdicos (Guira de Melena)	Berta María 2	350450	338530	6"	45	8
469				Carmelina Sierra	352010	324010	6"	75	8
470				Luis Flores	348500	335410	6"	45	8
471				Batey La Carmita	348640	333510	10"	75	8
472				La Carmita	348680	334060	10"	75	8
473				Buena Esperanza	348460	334360	8"	75	8
474				La Conchita	348220	335180	6"	45	8
475				José Raúl	347940	334820	6"	45	8
476				La Gallega	348640	333500	10"	75	8
477				Herminio	348700	334700	8"	75	8
478				Carrillo	349060	333600	10"	75	8
479				San Juán	350960	324570	8"	75	8

480				La Fregat	349880	333260	10"	75	8
481				Antonio Silva	349880	333570	10"	75	8
482				Ventura Pérez	351200	324500	8"	75	8
483				San Antonio	350480	325880	10"	75	8
484				Berta María 1	350110	326580	10"	75	8
485				Serafín Cabrera	349920	326660	8"	75	8
486				Batey Berta María	350010	326350	4"	30	8
487				Victor Gil	349950	325780	6"	45	8
488				Buena Esperanza 2	348450	334350	6"	45	8
489			CPA Ubaldo Díaz Fuentes (Guira de Melena)	157	344813	329064			
490				158	344946	328999			
491				159	345008	329127			
492				160	345189	329161			
493				161	344726	329355			
494				162	344789	329383			
495				163	344810	329173			
496				164	344601	329461			
497				165	344407	329536			
498				166	344295	329595			
499				167	344279	329596			
500				168	344222	329422			
501				169	344147	329080			
502				170	343913	329747			
503				171	344840	329079			
504				172	344732	329784			
505				173	344728	329773			
506				174	344797	330028			
507				175	344376	330198			
508				176	344120	330281			
509				177	344155	330074			
510				178	343968	330295			
511				179	343964	330815			
512				180	343881	330188			
513				181	343809	330326			
514				182	343501	330382			
515				183	343569	330742			
516				184	343648	330716			
517				185	343387	330868			
518				186	343065	330508			
519				187	343084	330501			
520				188	342752	330891			
521				189	342837	330664			
522				190	342708	330413			
523				191	342599	330922			
524				192	343660	330622			
525				193	344096	330406			
526				194	344162	330548			
527				195	344399	330774			
528				196	344391	330927			
529				197	343495	330385			
530				198	342878	330155			
531				199	343478	330368			
532				200	343843	329768			
533				201	343641	329839			
534				202	343409	329955			
535				203	343410	329952			

536				204	343452	329944			
537				205	343042	329983			
538				206	343070	329955			
539				207	342837	330000			
540			CPA Niceto Pérez (Guira de Melena)	1	347077	334020			
541				2	347783	333679			
542				3	348649	336187			
543				4	347454	335138			
544				5	348262	335973			
545				6	348548	335682			
546				7	349157	335512			
547				8	347821	335124			
548				9	348595	334735			
549				10	348733	333394			
550				11	349237	333010			
551				12	347040	332486			
552				13	347501	332174			
553				14	344725	332284			
554				15	347065	331471			
555				16	348706	331312			
556				17	346749	334688			
557				18	349467	333633			
558				19	348984	332620			
559				20	345801	332229			
560			UBPC. Héroes de Yaguajay	UBPC. Héroes de Yaguajay	344840	326665	6"	45	10
561			UBPC. Héroes de Bolivia	Camp Héroes de Bolivia	347476	324141	3"	10	8
562			EA Guira Servicios Técnicos (Guira de Melena)	Echazabal	343648	330716	4"	21	8
563				Odalis Lago Díaz 1	343387	330868	10"	150	4
564				Odalis Lago Díaz 2	343065	330508	8"	60	8
565				Guillermo F Cordova Leal 1	343084	330501	8"	75	8
566				Guillermo F Cordova Leal 2	342752	330891	6"	45	10
567			EA Granja Urbana (Guira de Melena)	Giraldo Lemus	346239	323032	6"	60	8
568				Mario Masola	345542	323103	6"	60	8
569				Santo García	345496	323097	6"	45	8
570				Yaniel Sánchez Pereira	344579	323208	6"	40	8
571				Yasiel Galiano	344214	322947	4"	27	8
572				Yasiel Galiano	344079	322981	4"	27	8
573				Lidiel Montano Rodríguez	345168	322885	6"	40	8
574				Lidiel Montano Rodríguez	344887	323162	4"	30	8
575				Javier Medero Díaz	344256	323992	8"	75	8
576				Nivaldo González Fernández	344366	324456	6"	60	8
577				Osmani Pérez Montano	344639	324483	6"	40	8
578				Pavel Hurtabo Borges	345083	324123	6"	40	8
579				Máquina Capote I	344700	323836	8"	75	8
580				Fernando Alvarez Millo	340208	323667	6"	35	8
581				Granja Urbana	344783	328624	6"	45	12
582				Leonardo Guillermo Capote 1	344804	328665	6"	45	12

583				Leonardo Guillermo Capote 2	344738	328275	6"	45	12
584				Hedilberto del Rosario	344922	328340	4"	25	8
585				Oscar Abreu Lescano	344608	328038	4"	30	16
586				José V Capote Alonso 1	344746	327995	4"	35	20
587				José V Capote Alonso 2	344616	327972	6"	45	16
588				José V Capote Alonso 3	344645	327864	4"	35	16
589			Establecimiento 202 Frigorífico	Frigorífico	346300	330900	3"	10	6
590			Pozos de apoyo al canal (Guira de Melena)	Marcos Campaña 6	349550	332193	10"	150	6
591				Marcos Campaña 5	349106	332014	10"	150	6
592				Marcos Campaña 4	348894	331856	6"	50	6
593				Marcos Campaña 3	348803	331504	10"	150	6
594				Marcos Campaña 1	348694	331237	8"	115	6
595				Marcos Campaña 2	348858	331239	8"	115	6
596				Pimienta	348473	329816	10"	120	6
597				Sonrisa de la Victoria 1	347632	328045	8"	75	6
598				Sonrisa de la Victoria 2	347637	328064	8"	75	6
599				Etiopía 1	346698	329375	10"	150	6
600				Etiopía 4	346400	329404	8"	75	6
601				Etiopía 2	345933	329464	10"	150	6
602				Etiopía 3	345570	328825	10"	150	6
603				La Pepilla 1	344679	328532	10"	150	6
604				La Pepilla 2	344492	328092	8"	75	6
605			CAN Avícola Quivicán	Granja Avícola La Soria	352300	334700	0.30	10	6
606				Granja Avícola La Mariana	364050	334200	0.30	10	4
607				Granja Avícola San Agustín	359000	326800	0.30	10	4
608				Granja Avícola Tamaulipa	353650	324300	0.30	10	6
609				Granja Avícola Victoria de Girón	356480	330580	0.30	10	6
610				Granja Avícola LPV	356000	339300	0.30	10	4
611				Gja Avícola Pedroso (Batabano)	364970	323650	4"	10	8
612		MINFAR	Pozos de apoyo al canal (Guira de Melena)	La Cunda 1	343408	327072	10"	150	6
613				La Cunda 2	343336	327104	8"	75	6
614				La Mangela 2	359343	335021	8"	50	6
615				La Mangela 1	359369	334910	8"	50	6
616			GMI Los Moros (Guira de Melena)	GMI Los Moros 1	343730	327530	8"	75	8
617				GMI Los Moros 2	343397	327103	8"	75	8
618			GMI Barnet (Guira de Melena)	Unidad Agropecuaria Militar 1	340388	324414	10"	120	8
619				Unidad Agropecuaria Militar 2	340370	324395	10"	120	8
620				Unidad Agropecuaria Militar 3	340669	325746	10"	150	8
621				Unidad Agropecuaria Militar 4	340655	325724	10"	150	8
622				Unidad Agropecuaria Militar 5	341138	324601	10"	130	8
623				Unidad Agropecuaria Militar 6	348899	322764	10"	100	8
624			GMI Sonrisa de la Victoria	Sonrisa 1	347300	326600	6"	45	8
625				Sonrisa 2	348250	326700	2"	3	8

			(Guira de Melena)						
626		MININT	Empresa Agropecuaria Industrial (Alquizar)	Granja El Coral Celia Sanchez	347699	322886	6"	60	8
627			Granja El Laurel (Quivican)	Pozo 1	352910	340210	6"	30	4
628		AZCUBA	CPA 17 de Mayo (Quivican)	Roman Organopónico	362270	332380	8"	75	6
629				El Patio La Remonta	362060	331740	6"	30	6
630				Mundela	363330	332670	8"	75	7
631				Arrocera	364140	330740	8"	75	7
632				Abasto CPA	363400	331490	4"	18	4
633			CPA 26 de Julio (Quivican)	Acueducto CPA 26 de julio	360300	331900	2"	10	12
634				Canarreo Arrocera	361500	330900	8"	75	10
635				Autoconsumo Pancho	362200	328500	8"	75	7
636			CPA Romárico Cordero (Quivican)	Marisol	358960	340670	6"	30	8
637				CPA	359450	340270	4"	20	6
638				La Clarita	359180	339910	6"	35	8
639				San Pedro	360210	339840	6"	30	8
640	ABASTO A POBLACIÓN	INRH	GEAAL Bejucal	Buenaventura	358586	339473	0.41	15	8
641				Cuatro Caminos	358460	341550	0.41	25	9
642			GEAAL Quivicán	Aguacate	363500	336600	0.50	12	9
643				Güiro Boñigal	356313	331287	0.41	10	9
644				Güiro Marrero	358880	328850	0.4	10	9
645				Paradero	361506	335170	0.4	10	3
646				Santo Cristo	355597	338897	0.51	50	24
647				Mi Retiro	355400	339520	0.41	18	13
648				Yolando Glez 1	360564	334194	0.6	75	16
649				Yolando Glez 2	360650	333820	0.51	75	roto
650				San Agustín	359420	327389	0.5	35	10
651				Raúl García	365406	332892	0.50	50	10
652				La Aguada	365386	332747	0.25	32	6
653				Santa Monica	359660	337167	0.4	52	8
654				Fajardo	351340	335070	0.4	50	24
655				Pablo Noriega	357290	329500	0.5	35	12
656			GEAAL Batabanó Mayabeque	Camacho	359800	322940	0.3	15	6
657				Pedroso	365000	323400	0.3	10	8
658				Pozo Redondo	365950	325300	0.3	10	8
659			GEAAL Habana (Aguas de la Habana) Quivicán Mayabeque	K21W1 (1)	352150	335644	0.5	187	24
660				K21W2 (2)	351647	335631	0.5	184	24
661				K22E1 (3)	352360	334721	0.5	208	24
662				K23E1 (4)	352374	333768	0.5	184	24
663				K23E2 (5)	352955	333782	0.5	171	24
664				G1 (6)	350020	333097	0.5	168	24
665				G2 (7)	350007	333693	0.5	150	24
666				G3 (8)	349377	333516	0.5	162	24
667				K24W1 (9)	351723	332494	0.5	171	24
668				K24W2 (10)	351242	332507	0.5	200	24
669				K24W3 (11)	350763	332469	0.5	186	24
670				K26W1 (12)	351426	330518	0.5	180	24
671				K26W3 (13)	350694	330399	0.5	200	24
672				K26W4,5 14)	350092	330191	0.5	173	24
673				K26W6 (15)	349475	329865	0.5	174	24
674				K26W7 (16)	348861	329402	0.5	176	24
675				K26E2 (17)	352320	330308	0.5	200	24

676				K26E4 (18)	353039	330308	0.5	169	24
677				K26E5,5 (19)	353664	330058	0.5	148	24
678			GEAAL Guira de Melena Artemisa	Acueducto Güira Nuevo	331500	345550	8"	52,2	12
679				Acueducto Güira Viejo 2	331500	345557	8"	50,4	4
680				Acueducto Güira Viejo 3	330800	344600	8"	36,0	6
681				Acueducto Zona de desarrollo	329900	345880	4"	54,0	5
682				Acueducto El Gabriel	332600	348800	8"	270,0	22
683				Acueducto Cajío	322350	349200	4"	30,0	15
684				Acueducto La Cachimba	327500	346600	4"	300,0	20
685			GEAAL San Antonio de los Baños Artemisa	Acueducto El Rancho	338400	332400		14,0	10
686				Acueducto El Valle	340170	348750		83,0	12
687				Acueducto La Encrucijada	343150	349750		36,0	9
688				Acueducto Campamento	336750	339800		36,0	9
689			GEAAL Alquizar Artemisa	Amparo 1	331660	336280		252,0	16
690				Las 400	331900	337050		264,0	16
691				Guanimar	324000	331440		36,0	5
692				Dagame N.P.	328500	329700		36,0	3
693				Mayorquín	330700	341700		36,0	8
694				Dagame Viejo	330750	329550		36,0	5
695				Pulido	329450	337300		36,0	6
696				El Bejerano	331980	334850		36,0	4
697				La Europa	324050	334650		22,0	8
698	INDUSTRIAS	MINAL	Emp Conservas Caribe (Quivican)	Pozo 1	357400	330600	4"	30	7
699				Pozo 2	356200	330450	6"	20	7
700		AZCUBA	UEB Central Azucarero Manuel Fajardo Quivicán	Fajardo	351330	334200	6"	75	6
701			ICIDCA Quivicán	ETICA	356720	328460	6"	60	8
702			Cuba 9 (Quiv)	Central Cuba 9	352960	331040	6"	45	10
703		MINAG	TABACUbA Quivicán	Resecadora de Tabaco Rubio	352300	333500	6"	20	8
704		MINNEN	UEB Generación Este Quivicán	UEB Generación Este Quivicán	351770	332300	4"	25	4
705	OTROS USUARIOS	MINED	MINED Quivicán	Ohhiguins	358600	333800	4"	5	4
706				IPA	358800	332250	4"	5	4
707				XX Aniv	356820	335200	4"	5	4
708				J G G Galló	356390	337270	4"	5	4
709		MINAG	E Porcino Habana	Porcino Quivican	358290	324070	4"	10	8
710				Porcino Los Báez Pozo 1	356050	331500	6"	15	6
711				Porcino Los Báez Pozo 2	355950	331500	6"	30	6

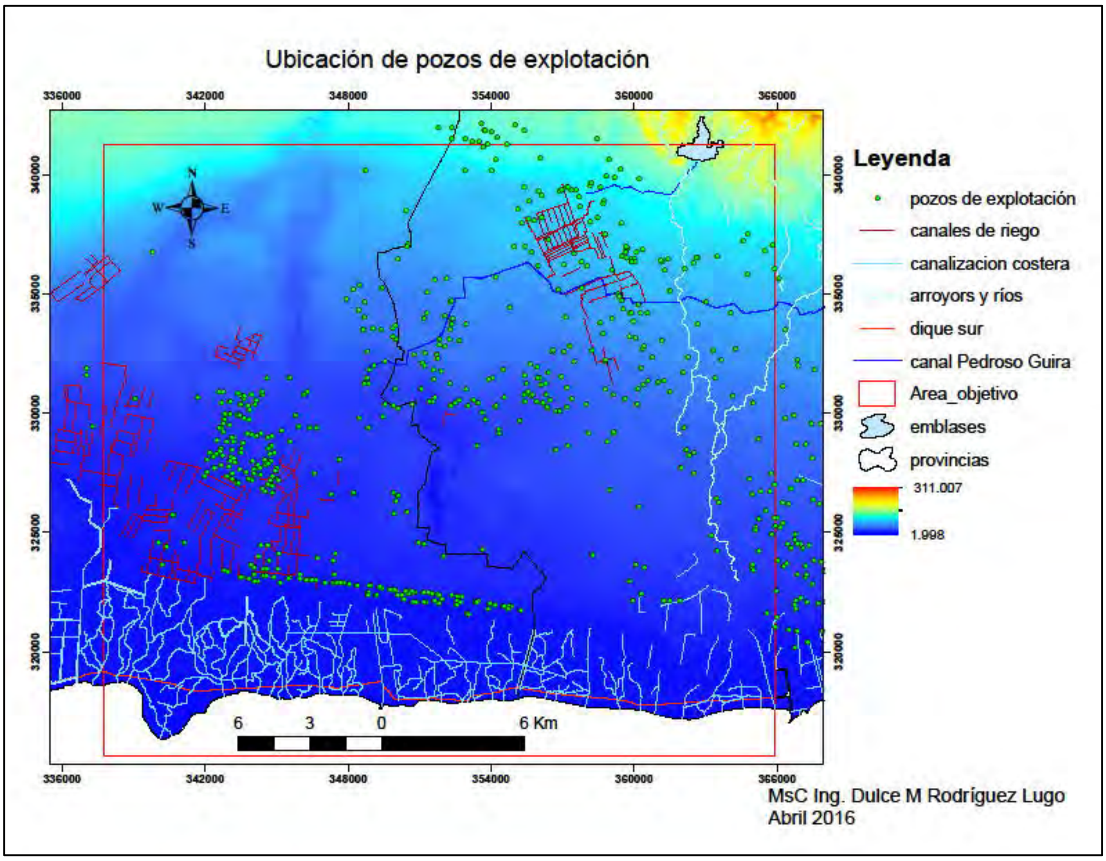

Figure 2-36: Map of the exploration wells

b. Groundwater use

In the last 5 years, groundwater extractions have maintained a stable trend. The most significant values are the use of groundwater for agricultural irrigation and the supply to the population, the rest of the uses have minimum values. However, it is necessary to emphasize that agriculture has had a downward trend in the last 2 years, due to the structural changes in its production forms and the incorporation of more efficient irrigation technologies such as the central pivot and roller machines, besides executing campaigns to electrify irrigation systems.

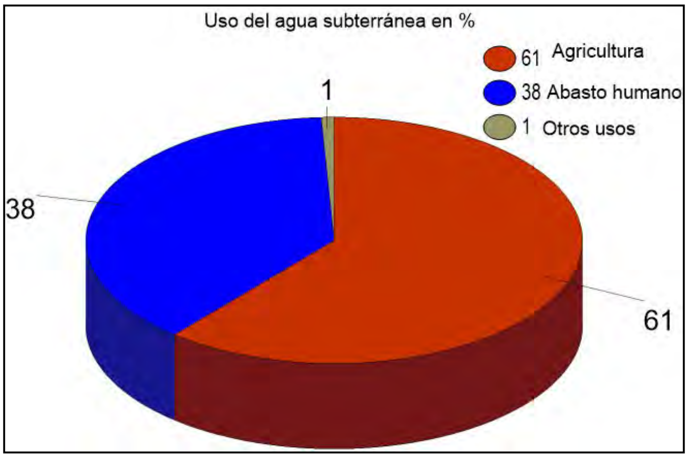

Figure 2-37: Groundwater use

In general, the largest volume of extraction is in charge of the Ministry of Agriculture with 61% of all water that is balanced in the basin in the study area. The Cuenca Sur Aqueduct delivers 86% of all water used for the supply to the population of the capital of the country, Havana, which shows that both of them are the main consumers.

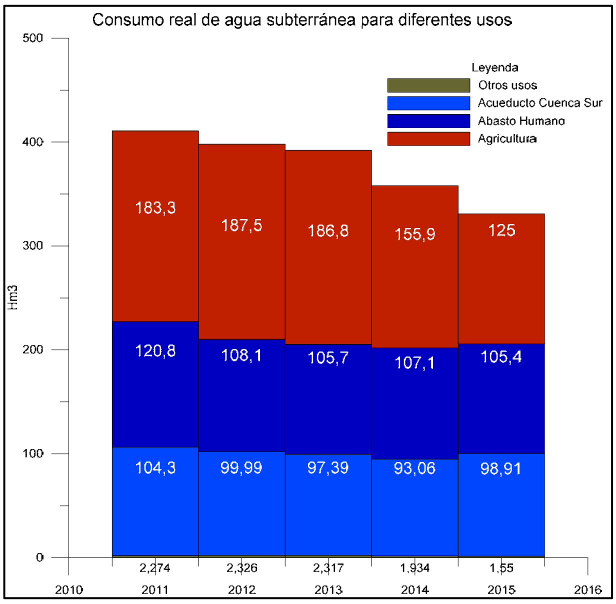

Figure 2-38: Actual groundwater intake for different uses

Out of the total volume of groundwater extractions, 61% is for human intake, 38% for irrigation and only 1% for other uses.

b.1 Water treatment plants (Human supply)

Groundwater used to supply the population is extracted through wells, whose water is subsequently disinfected by adding it sodium hypochlorite once it reaches the distribution networks.

There is a total of 49 supply sources for the population in the study area, 47 of them are located in the hydrogeological section HS-3 with an exploitable resource of 375 hm3 and 2 in the hydrogeological section HS-4 with an exploitation resource of 107 hm3 according to the resource evaluation of the 1992 Specified Regional Scheme.

The Cuenca Sur Aqueduct is the client that reaches the highest volumes of extraction with a system composed of a battery of 19 wells pumping 24 hours a day with an installed capacity of about 220 L/s each. The population to be supplied is of 1 248 838 inhabitants (according to the 2014 Statistical Yearbook) in the municipalities Playa, Centro Habana, Habana Vieja, Boyeros, Cerro, 10 de Octubre and Arroyo Naranjo, 58% of the population of the country's capital.

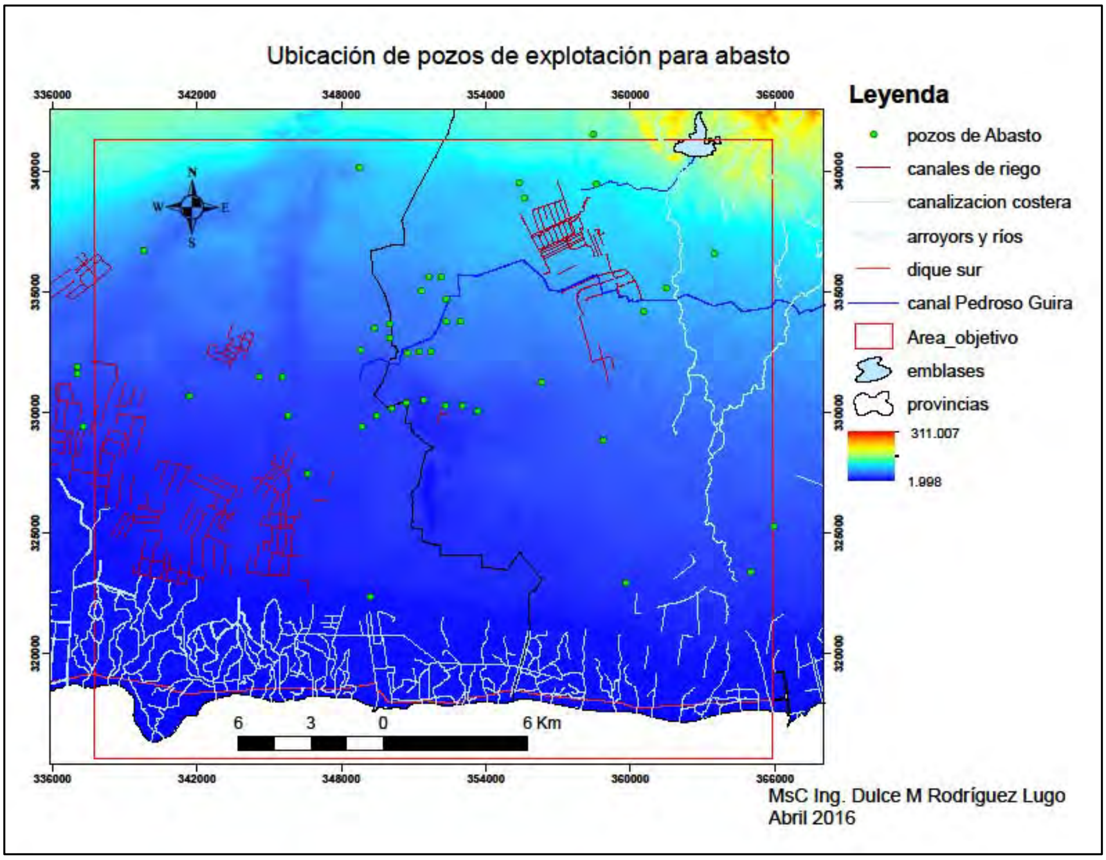

Figure 2-39: Map of the supply wells to the population

Regarding the water consumed for the human supply in the last 5 years, the Business Group of the Aqueduct and Sewage System (GEAAL) of Mayabeque and Artemisa (with 49 supply sources in the study area) have extracted an average of 116,379 hm3 in recent years, which represents 4% of the total. However, Aguas de la Habana is the largest consumer with an average of 99,071 hm3, 96% of the total water intake of the population in the area. The Cuenca Sur Aqueduct extracts each year 26.4% of the exploitable resource of the HS-3 basin (375 hm3).

There are 4 wells for human supply in the study area that are uninstalled. They belonged to 4 schools in the countryside, which are now closed, as they have varied their activity after the structural change of the Ministry of Education in the province.

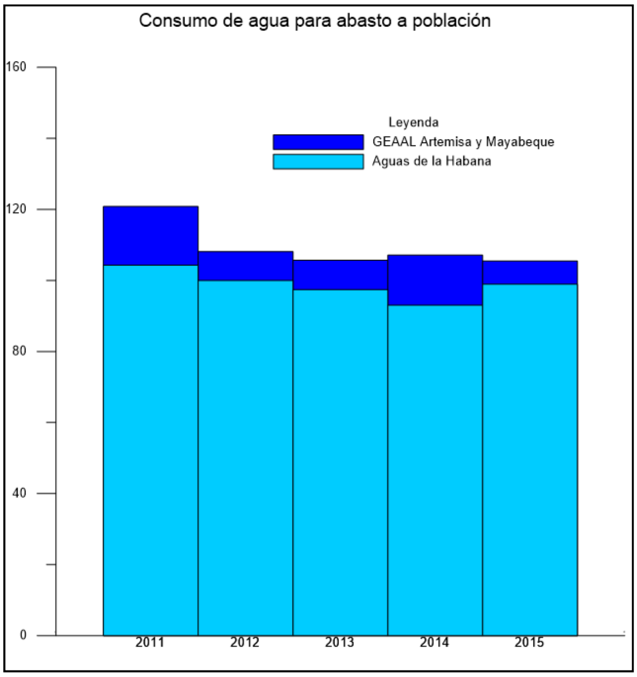

Figure 2-40: Graph with the discharge changes in number and volume from the wells that supply the population

b.2 Agriculture (irrigation)

Soils in the area have a high degree of productivity for agricultural development and the volumes used for irrigation are around 167,724 hm3 as an average in the last 5 years.

Water volumes for irrigation depend on the net standards, which are related to the efficiency of the irrigation system, the activity levels, the hydrophysical properties of the soil and the type of crop to be planted.

Table 2-8: Main crops in the area (Mayabeque)

Crop	Net Standard Res.287/2015	Area planted in the area (ha)
potato	4500 m^3/ha	184.400
citrus and fruits	8200 m^3/ha	113.660
sugar cane	4600 m^3/ha	5831.62
grains	3000 m^3/ha	1983.560
tubers	4410 m^3/ha	1074.360
yam	13200 m^3/ha	243.100
vegetables	4300 m^3/ha	1398.570
corn	4800 m^3/ha	900.740
banana	8400 m^3/ha	356.860
Total		12086.87

Table 2-9: Main crops in the area (Artemisa)

Crop	Net Standard Res.287/2015	Area planted in the area (ha)
potato	4500 m^3/ha	744.990
citrus and fruits	8200 m^3/ha	455.520
grains	3000 m^3/ha	1756.26
tubers	4410 m^3/ha	2440.870
yam	13200 m^3/ha	1198.380
vegetables	4300 m^3/ha	2031.090
corn	4800 m^3/ha	1049.290
banana	8400 m^3/ha	1217.5
tobacco	2100 m^3/ha	155.170
Total		11049.07

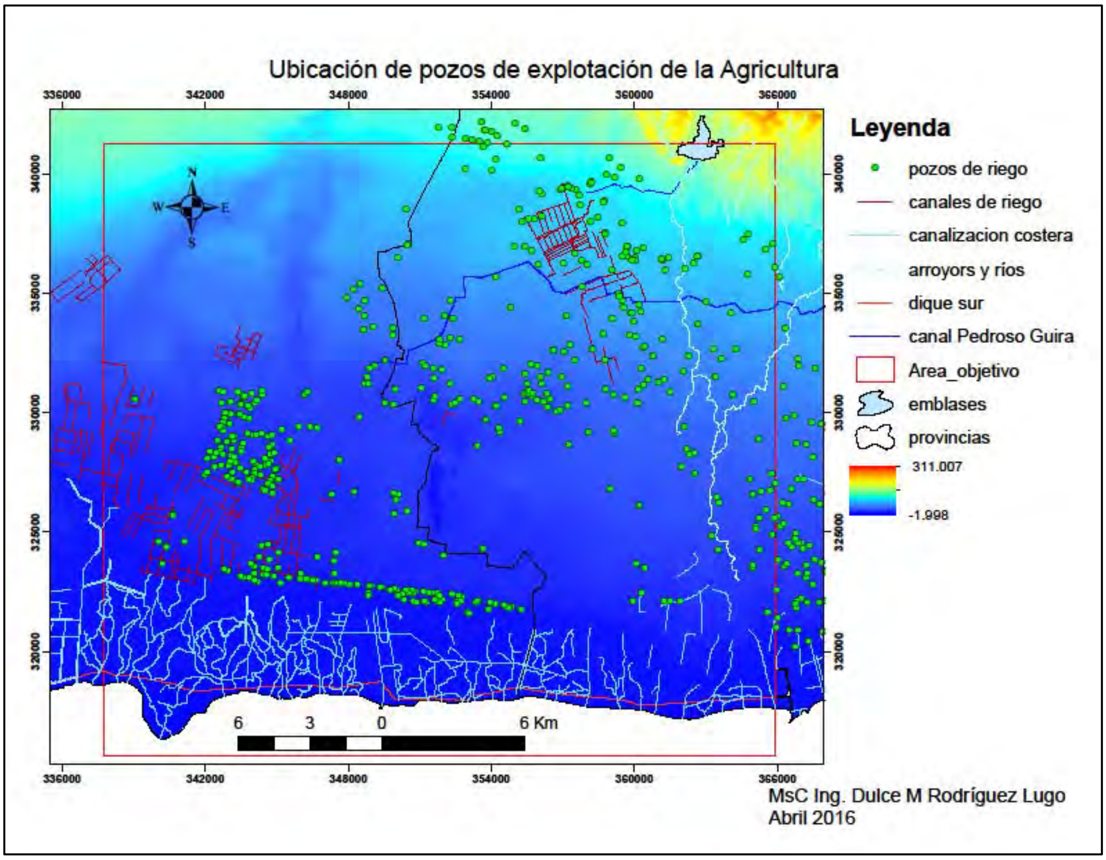

Figure 2-41: Map of wells used for agricultural irrigation

There is a total of 639 wells for agricultural irrigation in the study area, 600 of them are located in the HS-3 hydrogeological section and 39 in the HS-4 hydrogeological section.

According to the 2016 Water Balance, a summary grouped by organizations and activities shows that groundwater is used for irrigation in 23135.94 hectares (ha) for the production of sugar, vegetables, grains and other crops.

The tendency of extracting groundwater for agricultural irrigation has decreased. Although the aquifer levels have kept stable figures and have not entered an unfavorable zone, it is noteworthy that the rainfall averages over the last 3 years have decreased. This is has made agricultural entities to readjust their sowing plans based on short-cycle crops and of lower water demand to contribute to the sustainability of the water resource available in the basin.

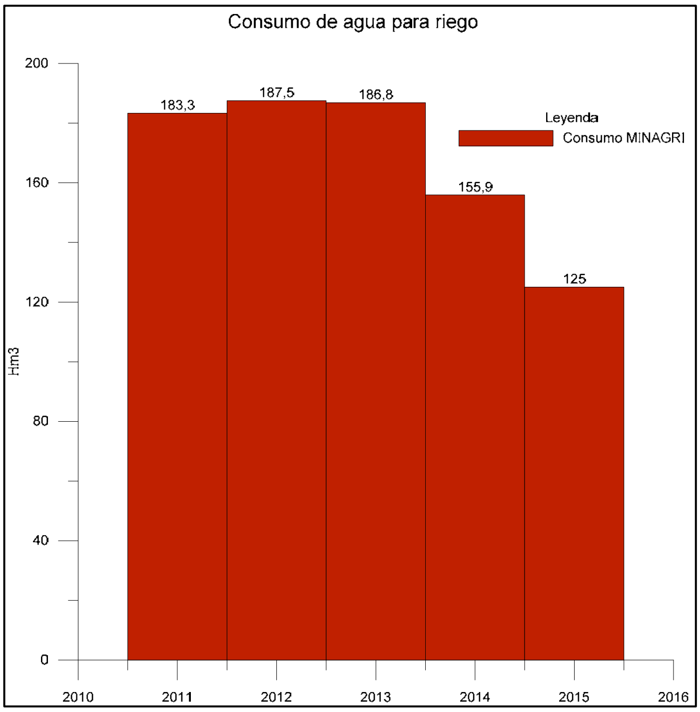

Figure 2-42: Graph with the discharge changes in number and volume from the irrigation wells.

b.3 Industry

There are a total of 7 wells in the study area where the water extracted is used for the industry. All of them are located in the hydrogeological section HS-3.

Industrial productions are not predominant in the area. There are only 6 industries of interest, all of which are focused on the sugar cane and its by-products, paper, electricity generation and other productions such as canned food, beverages and liquors, etc.

Extraction volumes in the last 5 years do not exceed one million m3 among all industries and are not quite representative in the groundwater exploitation.

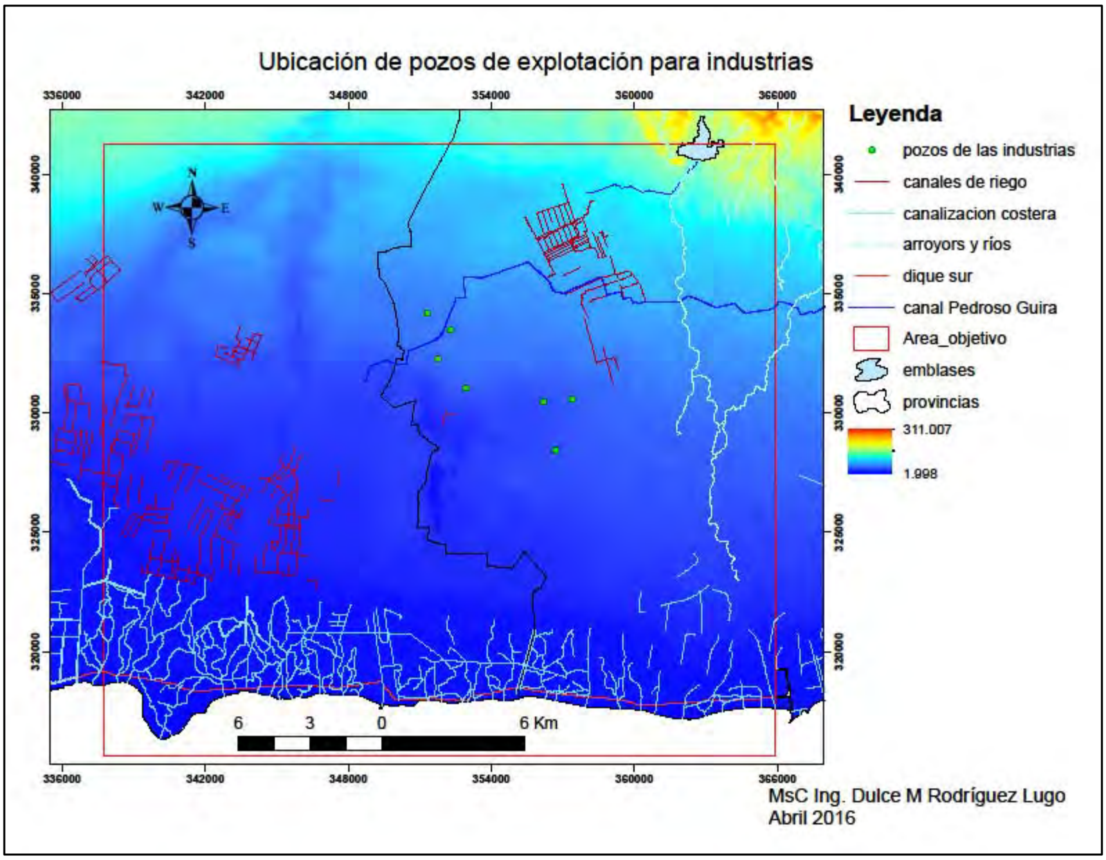

Figure 2-43: Map of the wells used in the industry

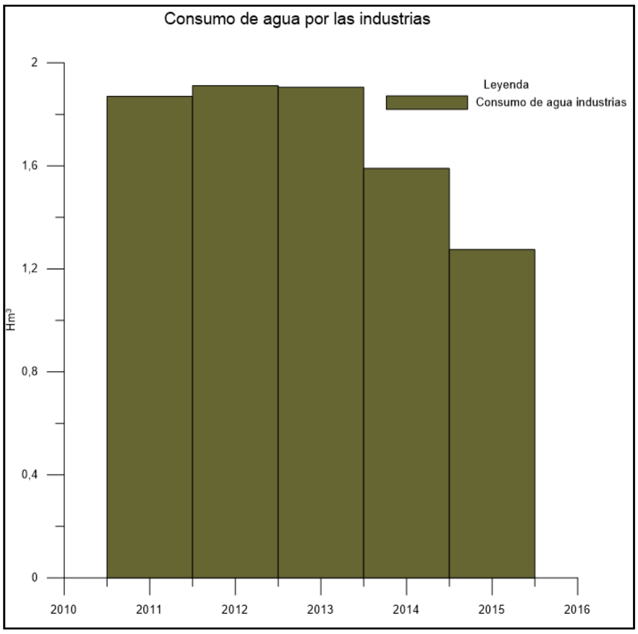

Figure 2-44: Graph with the discharge changes in number and volume from the wells used in the industry

b.4 Other uses

Other groundwater uses in the study area are related to the service providing, including 1 Pork Processing Center, 2 Research Centers (the Sugar Cane Experiment Station and the Liliana Dimitrova Horticultural Research Institute), both in the municipality of Quivicán and several educational centers located in Artemisa and Mayabeque.

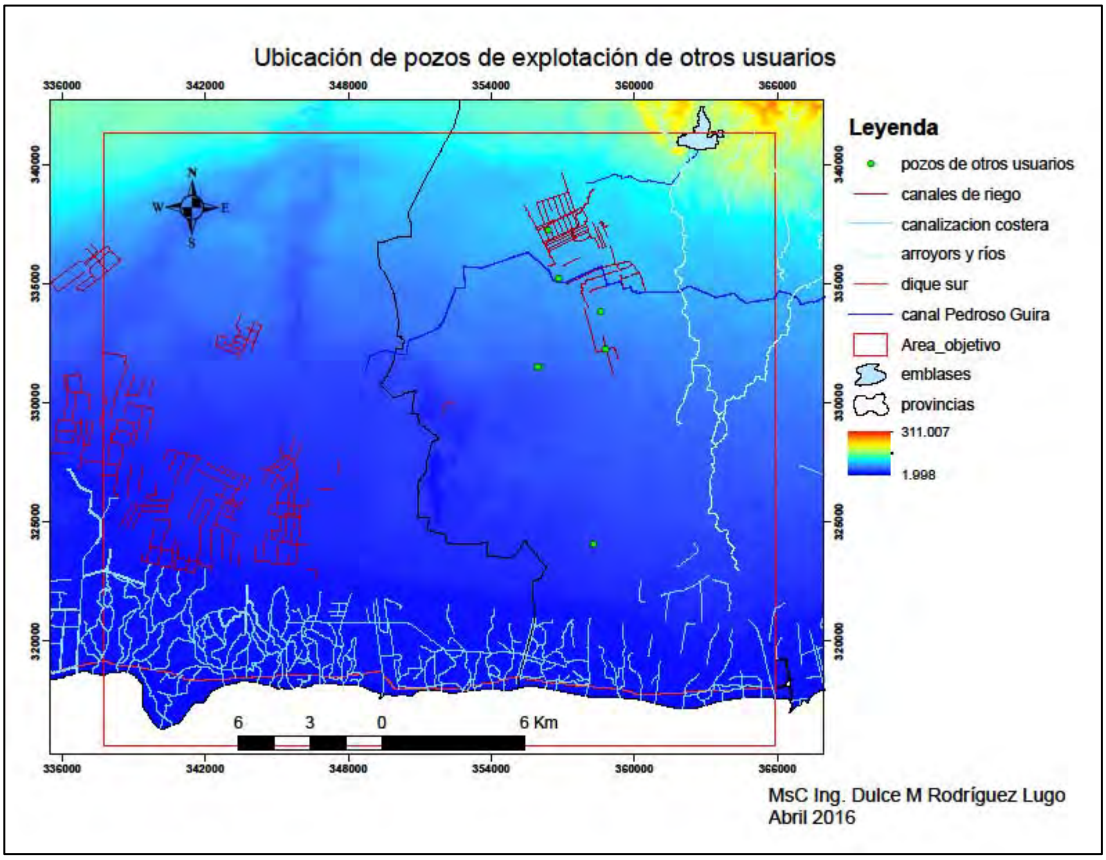

Figure 2-45: Map of the exploration wells with other uses

The following graph shows how the extraction volumes have declined in recent years, as the Ministry of Education has closed some schools in the countryside.

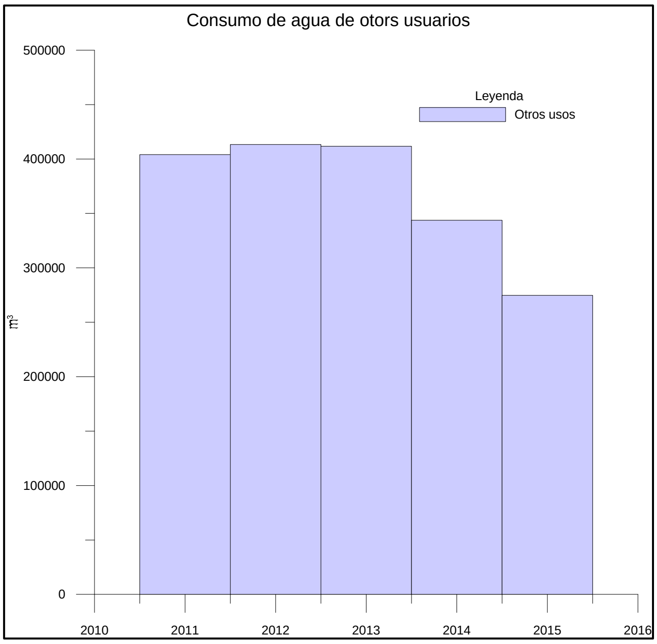

Figure 2-46: Graph with the discharge changes in number and volume from the wells with other uses

2.4 Groundwater Level Fluctuation

Groundwater in the study area has a free surface, little undulating or almost flat and is weakly leaned towards the discharge zone. The flow gradients in the lower altitudes of the basin are 0.001 to 0.0001 and lower, increasing towards the periphery. The minimum gradient zone s is limited by hydrohypse +5. An increase of the gradients in the area of propagation of the Paleogene sediments can be observed towards the North. That is to say, the gradients of the underground flow increase from South to North and the nature of its variation is reflected in the hydrohypse map.

The groundwater lay depth varies in a wide range, from 0 to 40-50 m. The regularities in the distribution of the depths in the flat areas, where the groundwater free surface is relatively flat, is determined by the particularities of the relief and by the absolute elevation of the terrain. In the territory, can be observed a zonality of the water depths. The greater depths are observed in the inner part of the plain, in the zone where the absolute elevations of the terrain are of 10 to 40 m. The lay depth gradually increases, from 0 to 5 m in the coastal area, from 5 to 20 m in the central area and from 20 to 40 m in the northern area, and it decreases towards the contact with the deposits from the pre-Neogene.

The groundwater level variation regime has a close connection with atmospheric rainfalls and reflects its changes, both, within a year and during a hyper-annual cycle.

In addition to natural factors, the regime of the groundwater levels is related to artificial factors such as: extraction, channel losses, infiltration of the irrigation water, etc. A comparative analysis of the regime observations, over a period of more than 30 years, shows that artificial factors (mainly taking the extractions into account) do not have a negative influence on groundwater levels in a hyper-annual hydrological cycle.

According to the climatic conditions of the country, the year is divided into two seasons, rainy and of little rain, as well as in a sequence of dry and humid years in a hyper-annual season. The upwards and downwards of the hyper-annual levels may have a tendency to the consequent downward of the absolute minimums. However, with the subsequent passing of hurricanes that cause heavy rains, the levels recover the initial value or even higher ones. This happened during the passing of hurricane Frederick in 1979 and during the hurricanes of the year 2005.

The maximum variations within a year in the territory are observed approximately in the central part of the circulation area and are in the order of several meters. In the hydrohypse area bellow 3 to 5 m, the variations by period are of 1 to 1.5 m. The amplitudes of the levels, in the hyper-annual cycle, have a more complex distribution. The maximum variations have been observed in the northern area, in the order of 15 to 20 m. In the area that is limited by the +5 hydrohypse, a gradual downward of the hyper-annual amplitudes of 0 to 3 m is observed.

The oscillation regime of the groundwater in the area is manifested by the data obtained in the observation wells of the systematic network. The oscillation in the levels shows us the direct link between the magnitude and the intensity of precipitations. The value of the amplitudes of the levels decreases from the periphery of the study area to the sea and is related to the proximity of the discharge area and to the transmissivity of the rocks. Due to this, amplitudes are practically analogous as well as the configuration of the curves in the intensely karstified limestones of the Güines and Cojímar formations, according to data from the LSU-1, HSC-543 HSC-541 observation wells. Their value does not exceed one meter with the occurrence of normal rainfall and do not exceed 2.50 m during the passing of hurricanes.

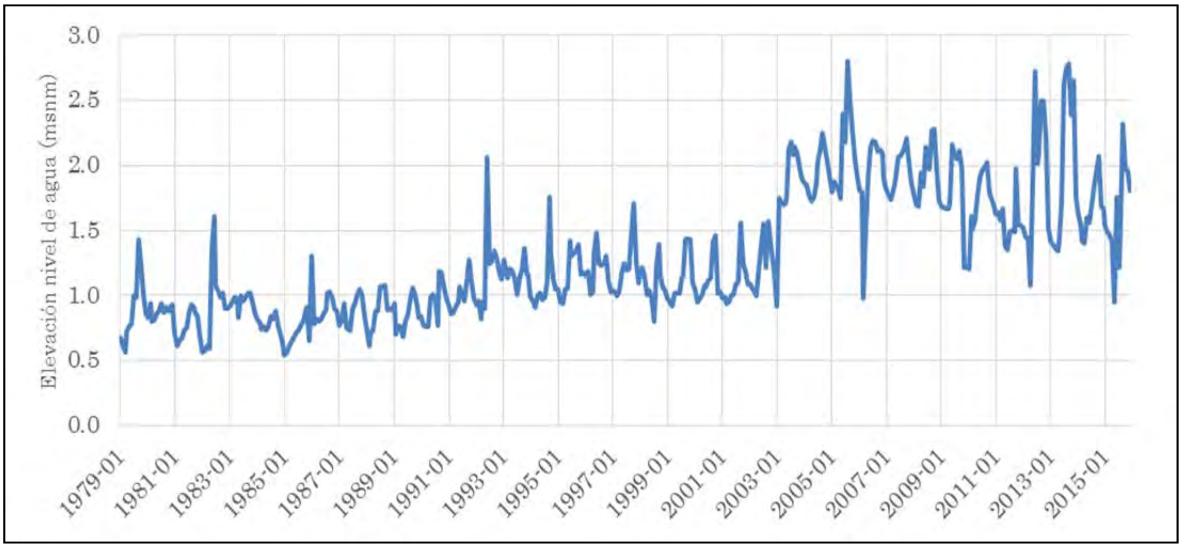

Figure 2-47: Groundwater level fluctuation of the LSU-1 observation well (mamsl)

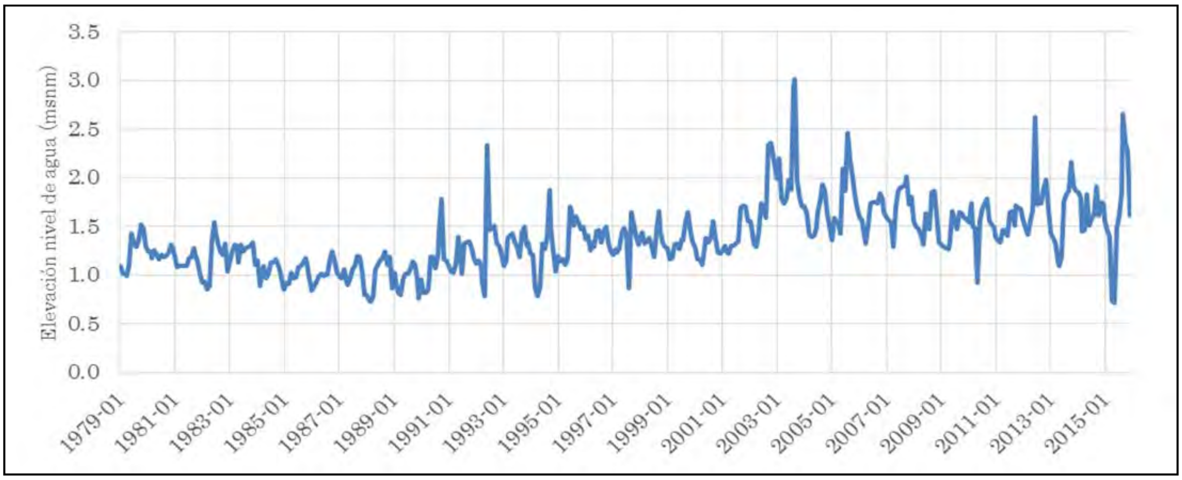

Figure 2-48: Groundwater level fluctuation of the HSC-543 observation well (mamsl)

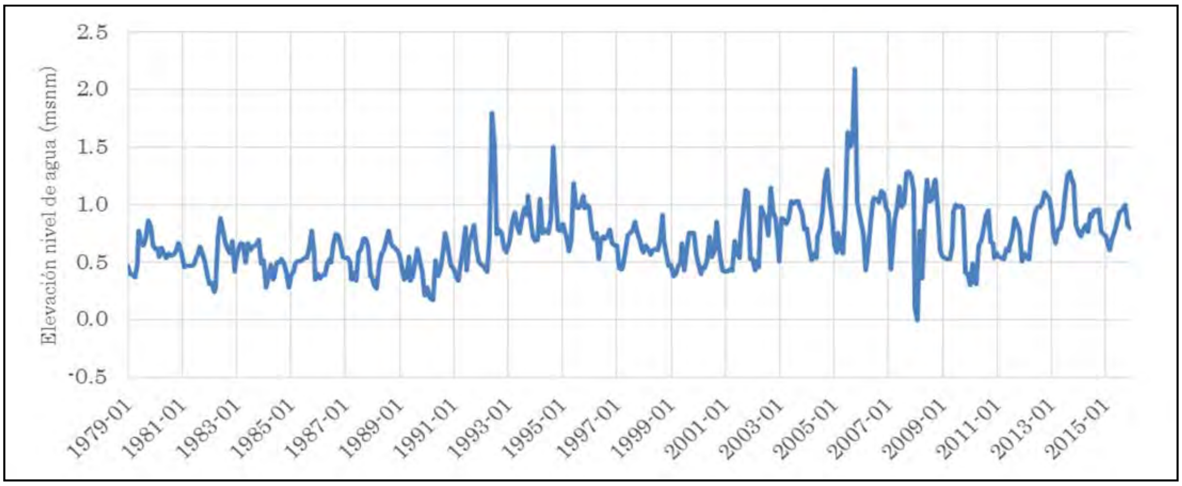

Figure 2-49: Groundwater level fluctuation of the HSC-541 observation well (mamsl)

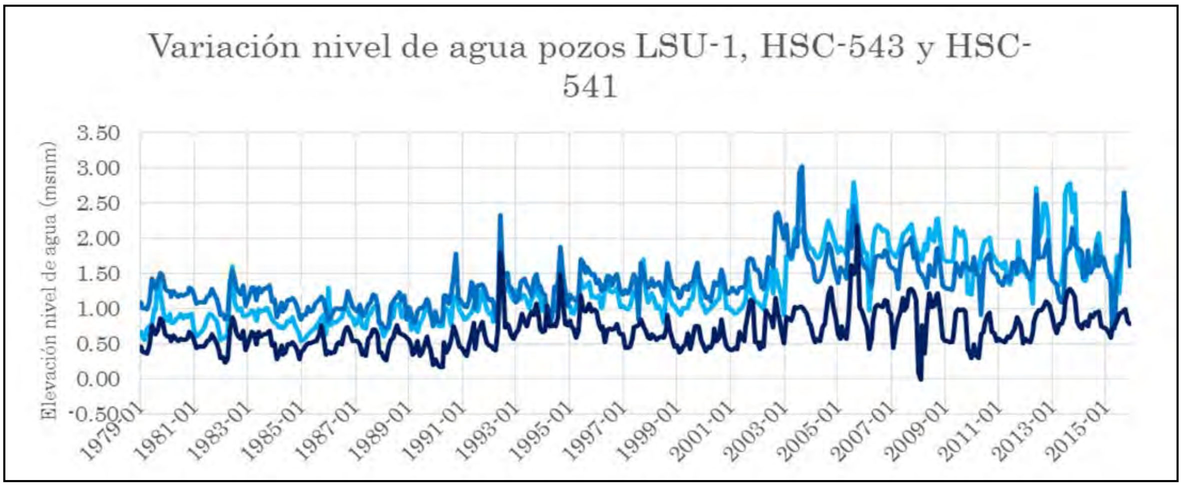

Figure 2-50: Overlapping of the water level fluctuations of the LSU-1, HSC-543 and HSC-541 wells (mamsl)

In the area where the geological cut is represented by marls, the oscillations of the levels is more abrupt and the amplitudes increase by some meters, as in the LSU-8 observation well. In the central area, where the deposits of the Colón formation are found, the elevations have a temporary nature and the amplitudes vary from 2 to 5 m.

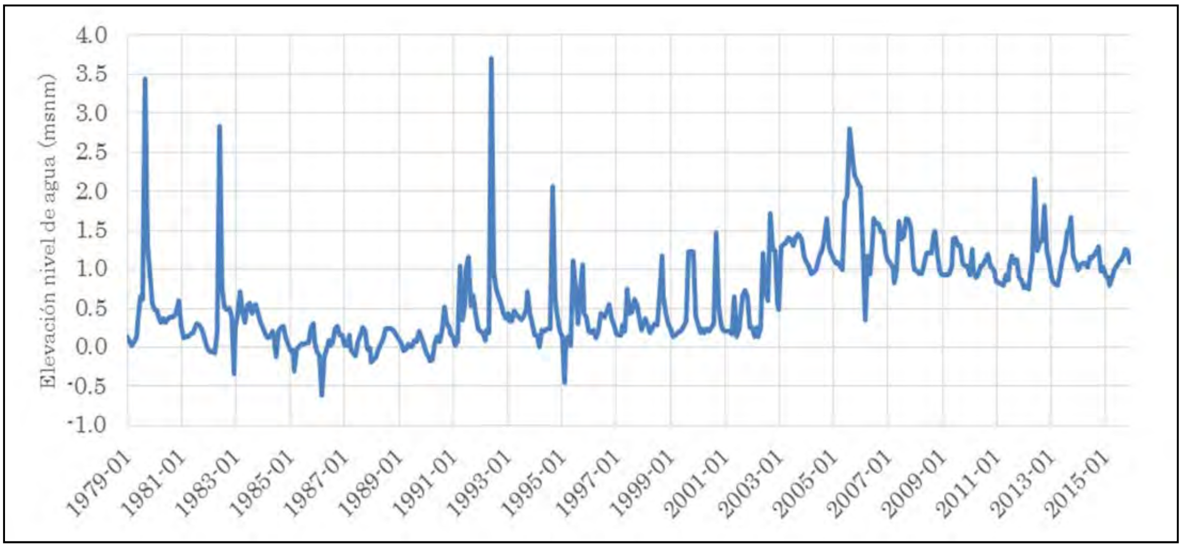

Figure 2-51: Groundwater level fluctuation of the LSU-8 observation well (mamsl)

Taking into account the particularities of the groundwater regime in the Neogene aquifer complex, it is possible to divide it into two main areas. The first area stretches to the North, from the underground runoff dividing line to the hydrohypse +5, where observation wells such as HSC-516, LSU-3, HSC-563, A-19A and HSC-586 are located. In this part, the oscillations of the levels vary in a hydrological cycle of 2 to 5 m, where the elevation of groundwater levels reaches 5 to 100 m and the flow gradients are of 0.002 to 0,006 and, in the pre-mountain area, of 0.04.

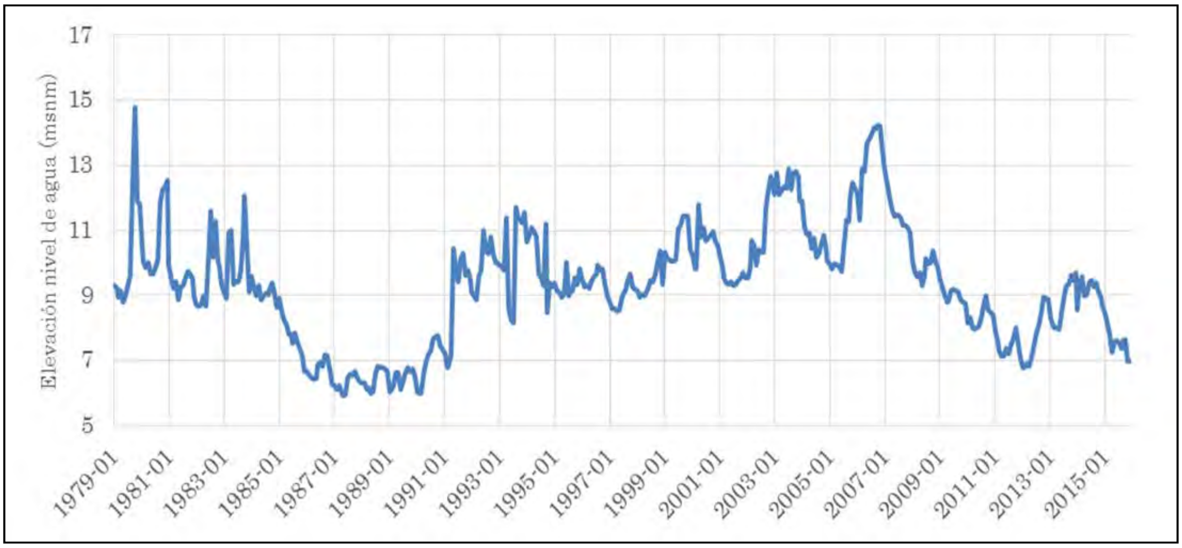

Figure 2-52: Groundwater level fluctuation of the HSC-563 observation well (mamsl)

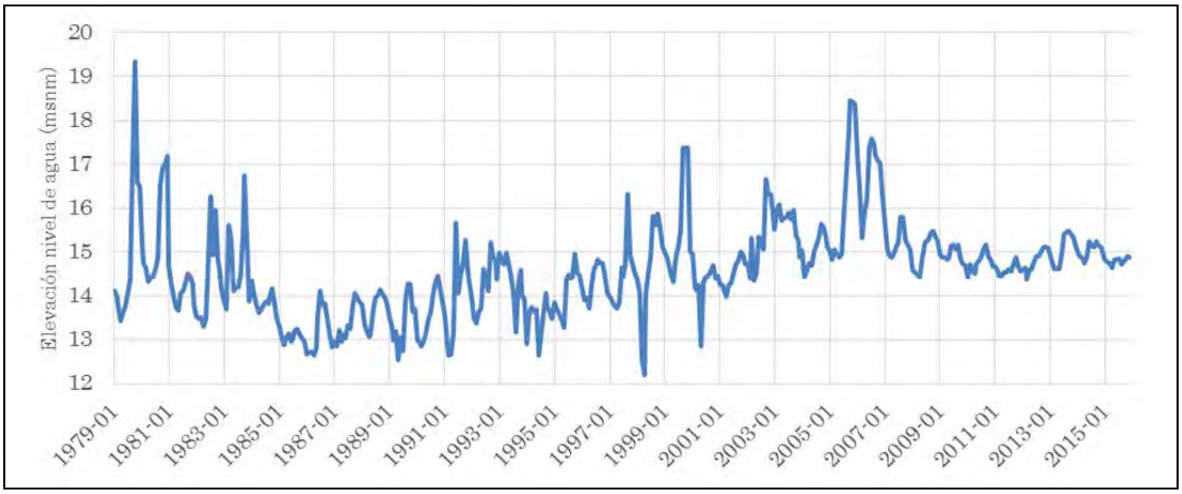

Figure 2-53: Groundwater level fluctuation of the LSU-3 observation well (mamsl)

The second area extends to the South from the +5 hydrohypse to the boundary with the saltwater, forming an approximately semi-circular hydrogeological structure limited by faults. In this area, the HSC-523, HSC-541, LSU-1, HSC-543 and LSU-8 observation wells of monthly frequency are located, the amplitude of the levels is not higher than 1 m in a hydrological cycle, and only when heavy precipitations occurs can reach up to 4 m. The flow in this area is practically flat, and the minimum gradients reached values below 0.0001.

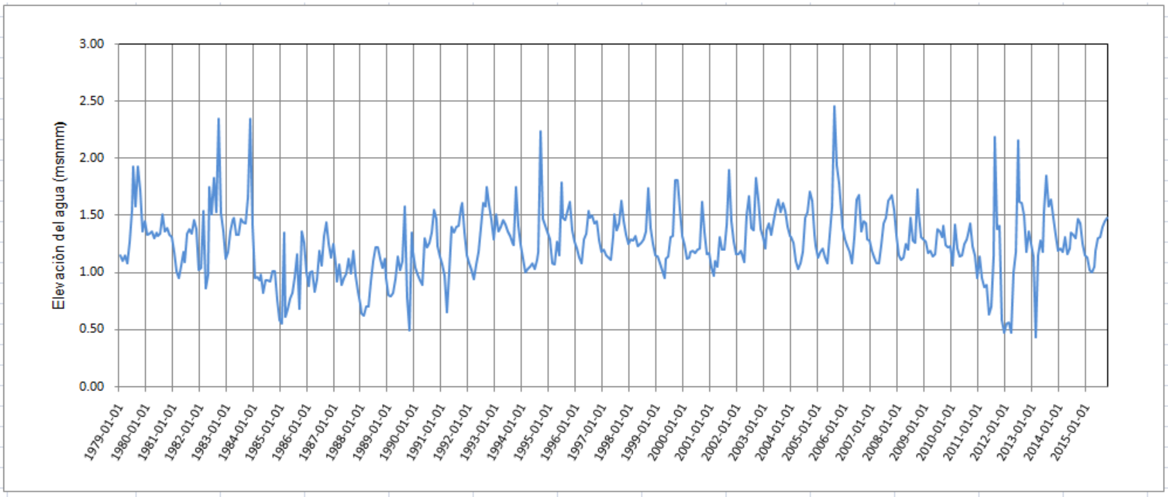

Figure 2-54: Groundwater level fluctuation of the HSC-16 observation well (mamsl)

The level variations of the HS-16 study well located in the municipality of Alquízar present oscillation levels of 2.46m as a historical maximum and 0.43m as a historical minimum.

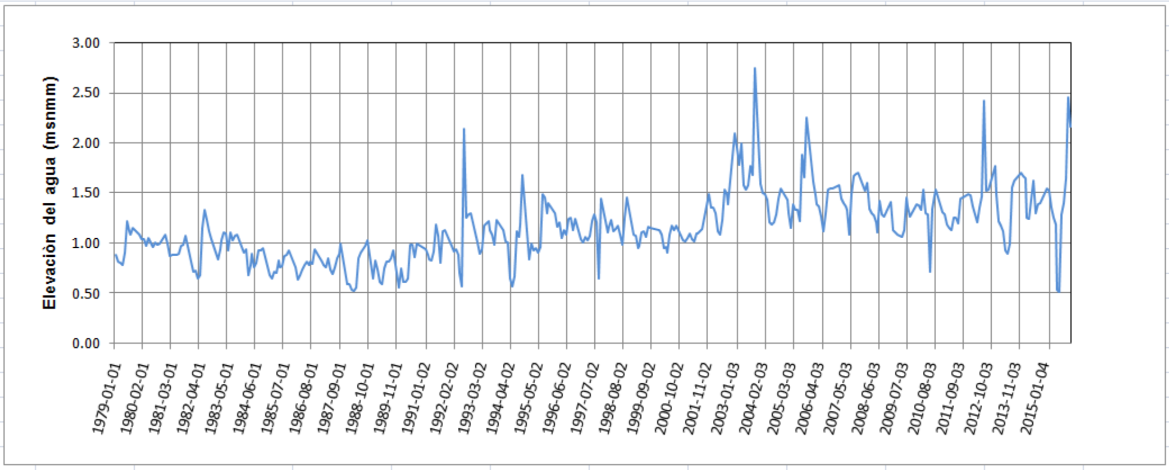

Figure 2-55: Groundwater level fluctuation of the HSC-543 observation well (mamsl)

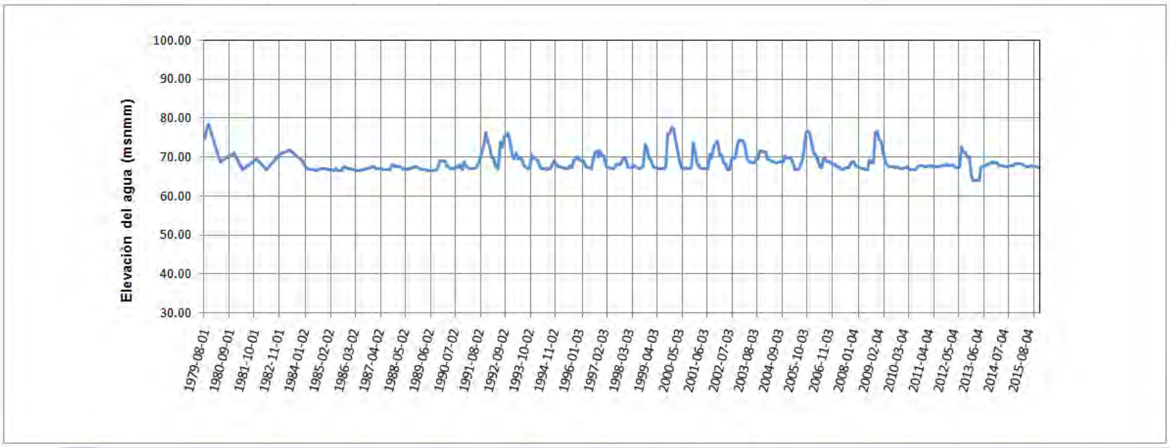

Figure 2-56: Groundwater level fluctuation of the HSC-501 observation well (mamsl)

The study well is located in the higher area of Cuenca Sur and it has recorded as a maximum water spot height 78.42m and the minimum value reached was 63.87m.

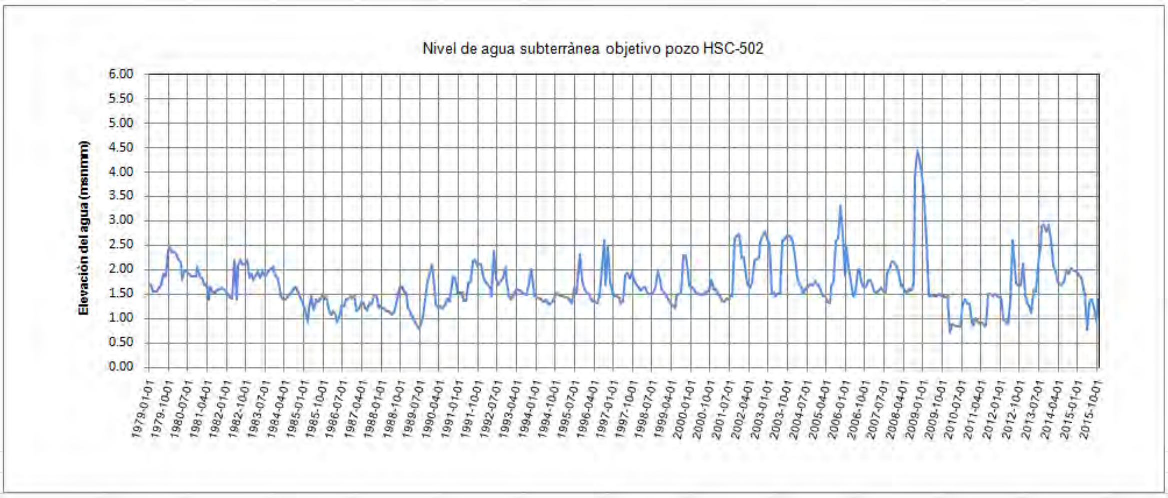

Figure 2-57: Groundwater level fluctuation of the HSC-502 observation well (mamsl)

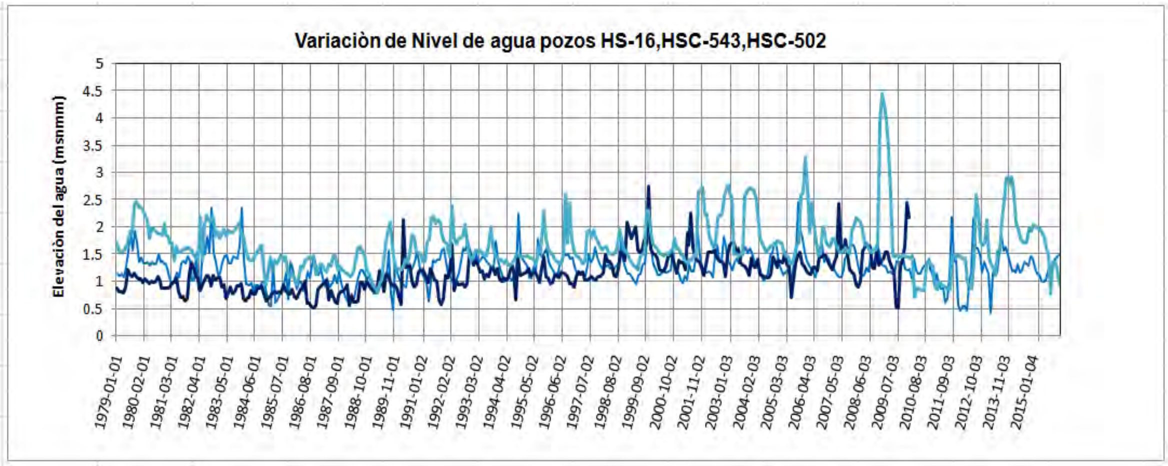

Figure 2-58: Overlapping of the water level fluctuations of the HS-16, HSC-543 y HSC-502 wells (mamsl)

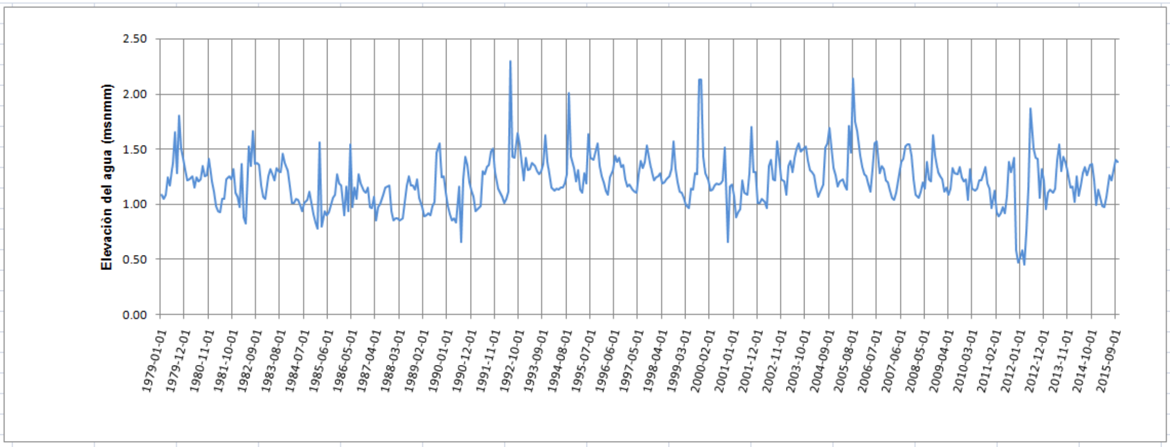

Figure 2-59: Groundwater level fluctuation of the HSC-505 observation well (mamsl)

The minimum spot height recorded is 0.60m and the maximum is 2.30m.

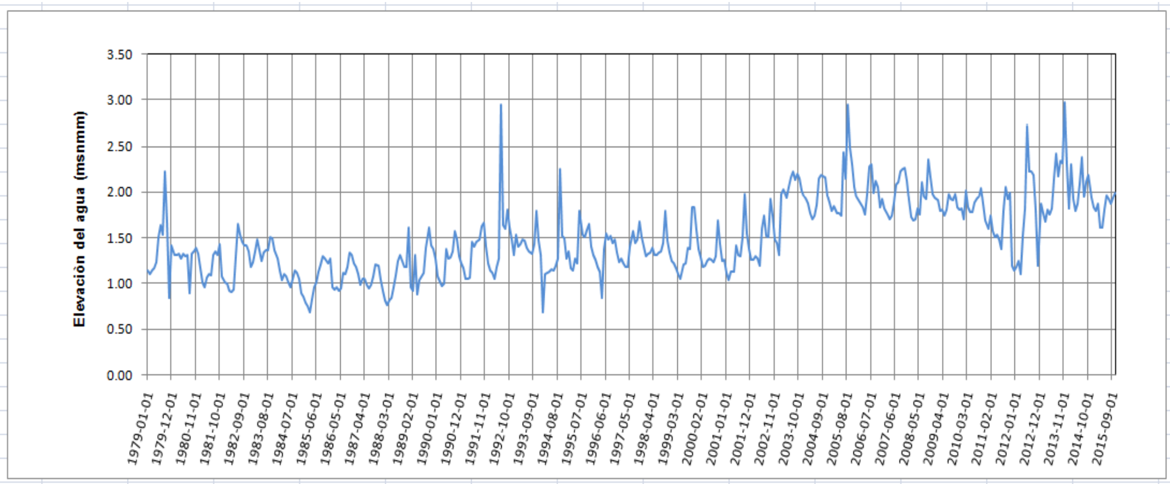

Figure 2-60: Groundwater level fluctuation of the LSU-6 observation well (mamsl)

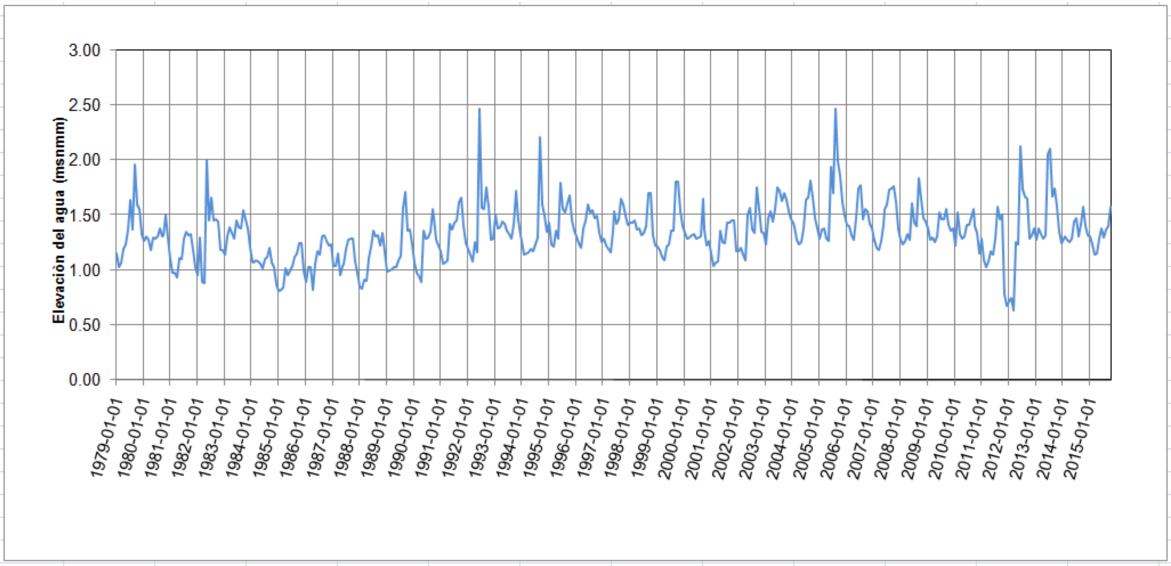

Figure 2-61: Groundwater level fluctuation of the HSC-509 observation well (mamsl)

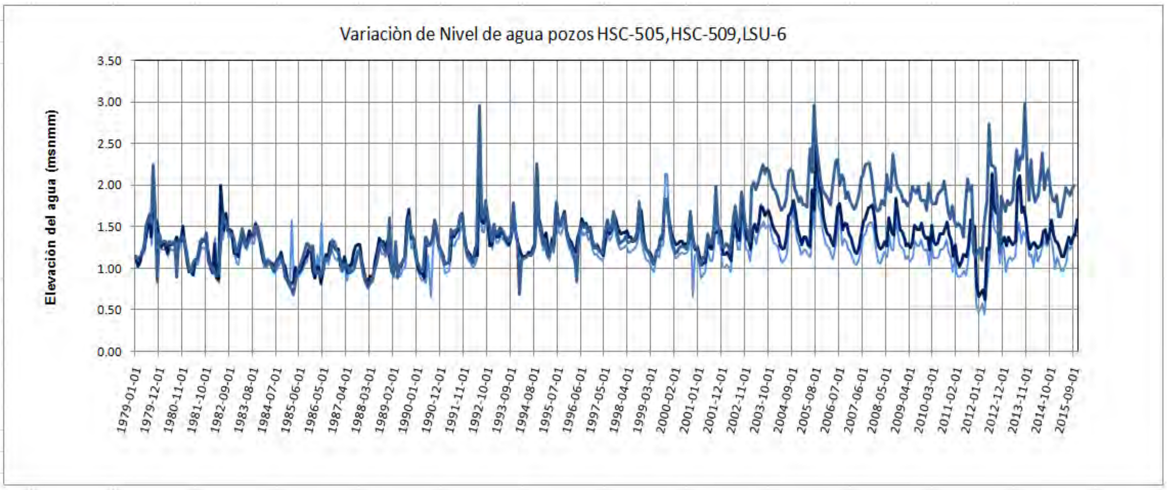

Figure 2-62: Overlapping of the water level fluctuations of the HSC-505, HSC-509 y LSU-6 wells (mamsl)

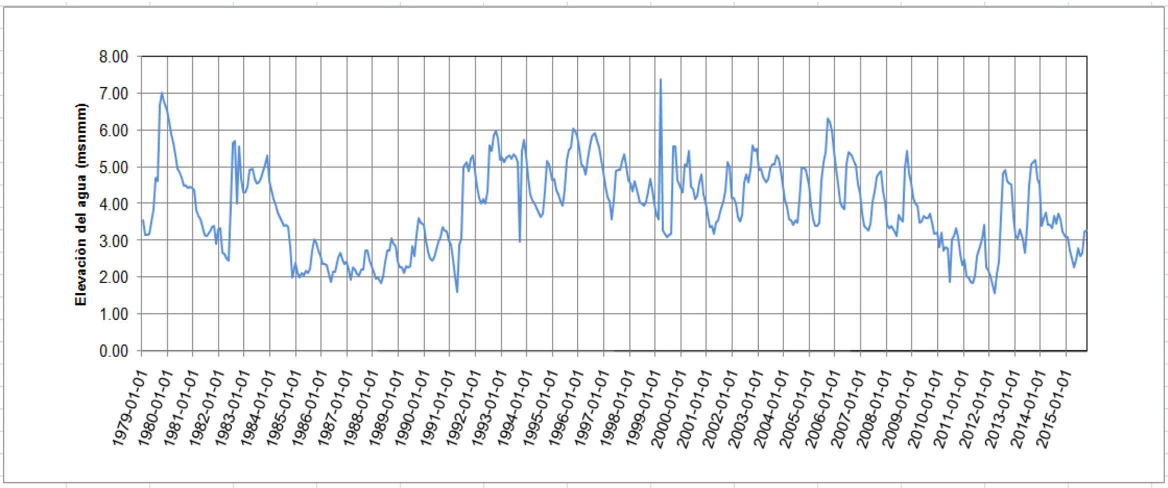

Figure 2-63: Groundwater level fluctuation of the LAR-4 observation well (mamsl)

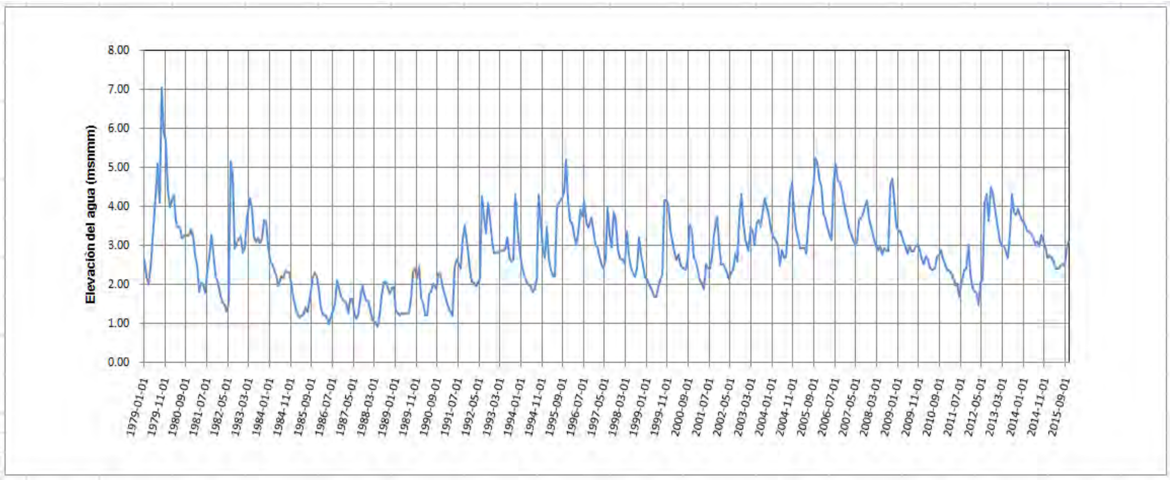

Figure 2-64: Groundwater level fluctuation of the LAR-1 observation well (mamsl)

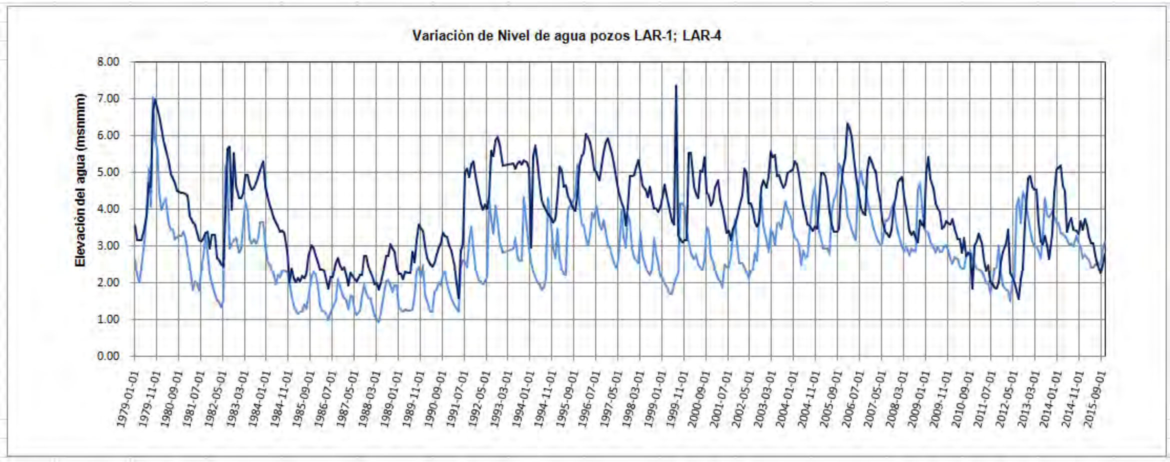

Figure 2-65: Overlapping of the water level fluctuations of the LAR-1, LAR-4 wells (mamsl)

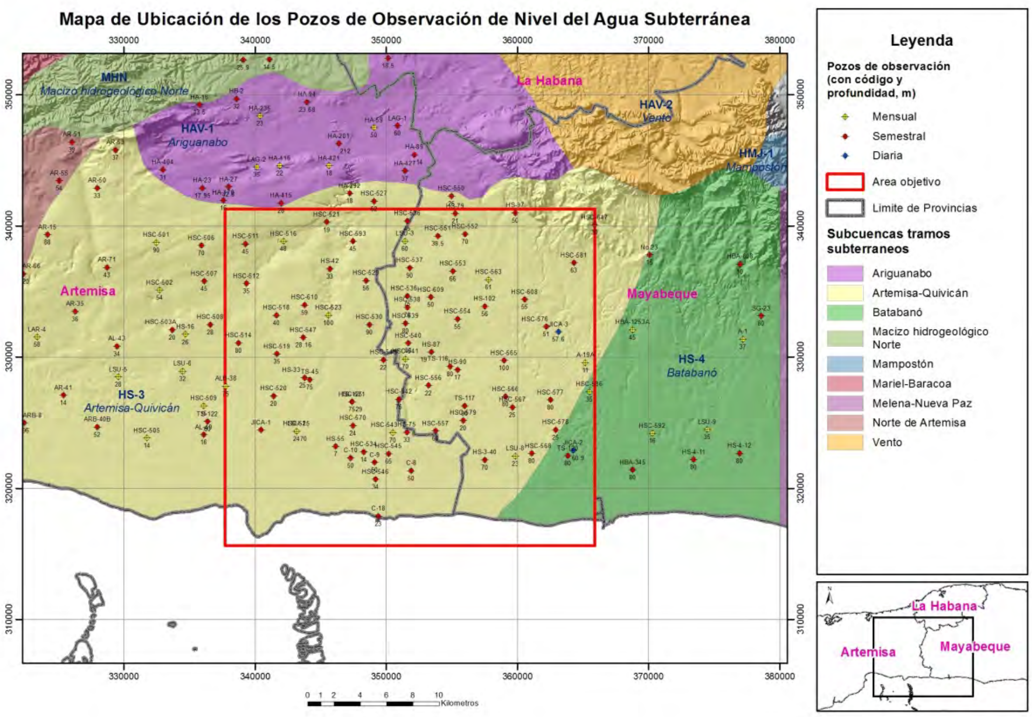

Figure 2-66: Map of the groundwater level observation wells

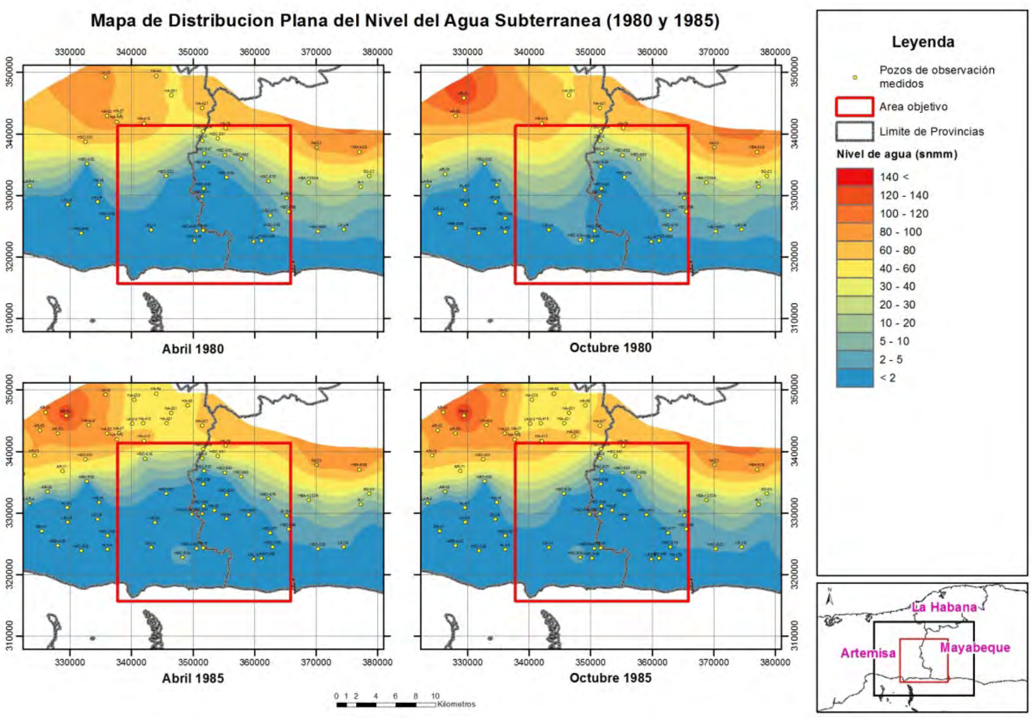

Figure 2-67: Map of flat distribution of the groundwater level (1980 and 1985)

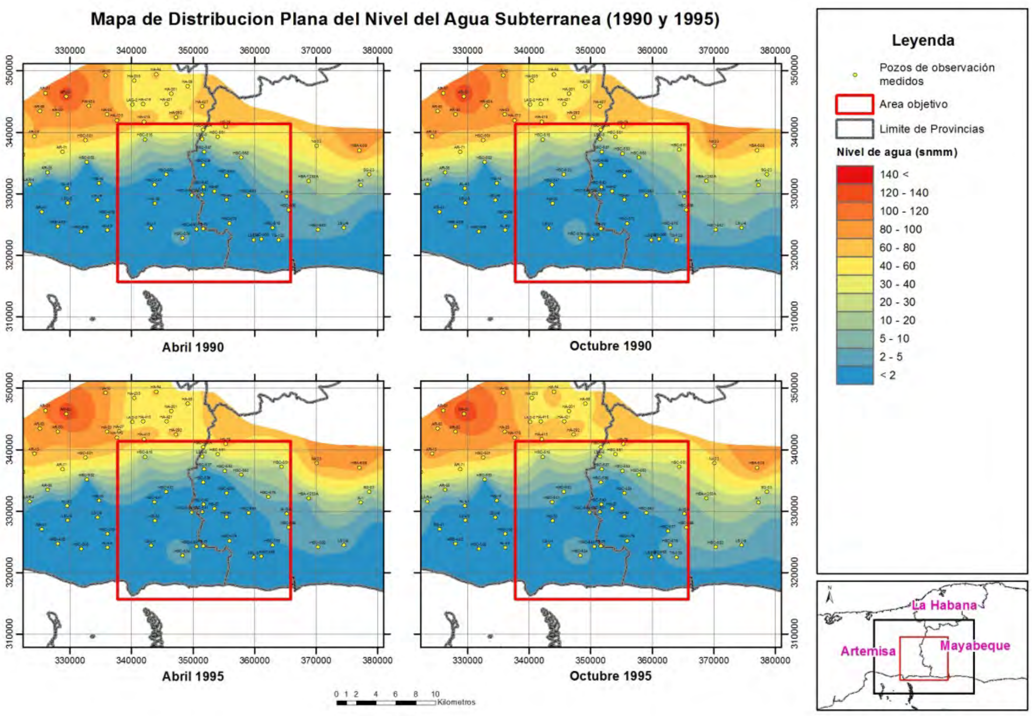

Figure 2-68: Map of flat distribution of the groundwater level (1990 and 1995)

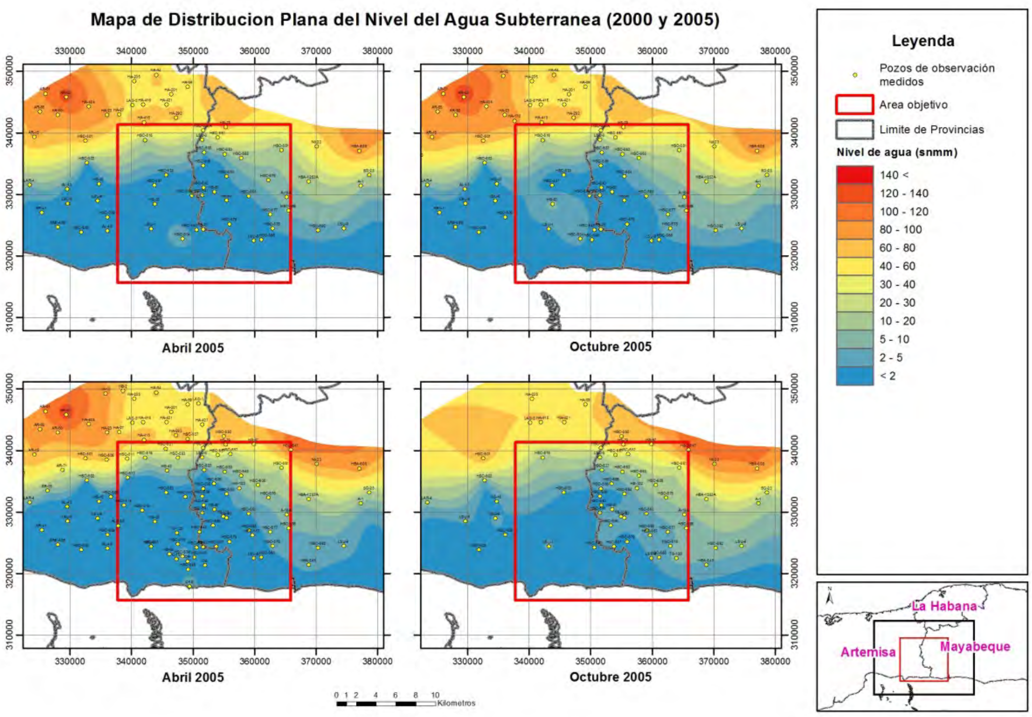

Figure 2-69: Map of flat distribution of the groundwater level (2000 and 2005)

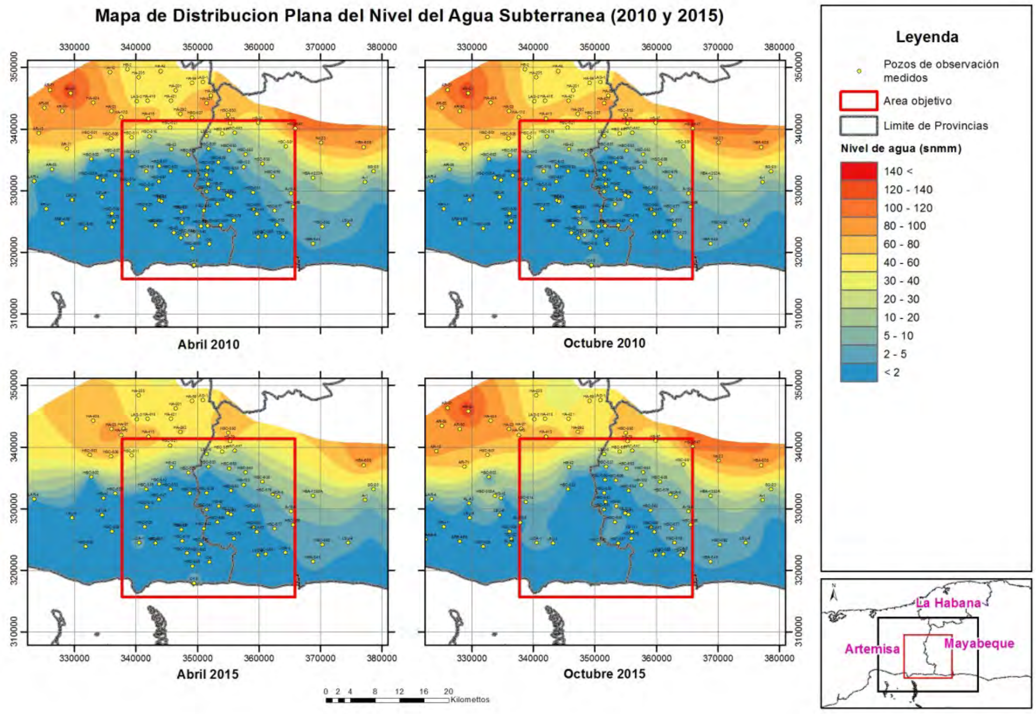

Figure 2-70: Map of flat distribution of the groundwater level (2010 and 2015)

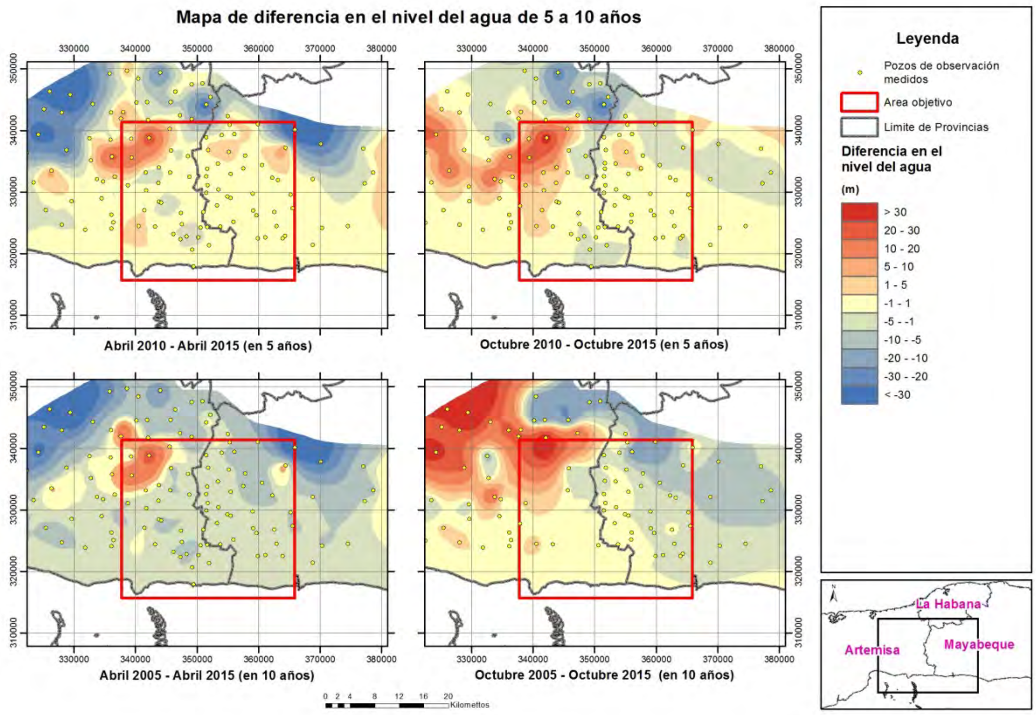

Figure 2-71: Map of difference in the water level from 5 to 10 years

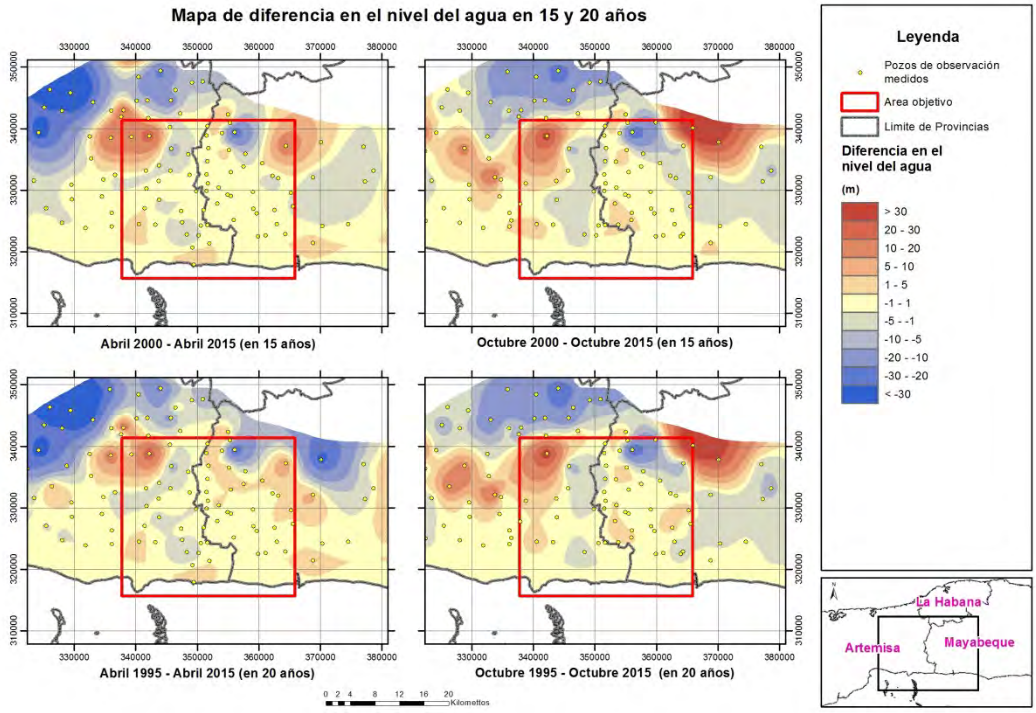

Figure 2-72: Map of difference in the water level from 15 to 20 years

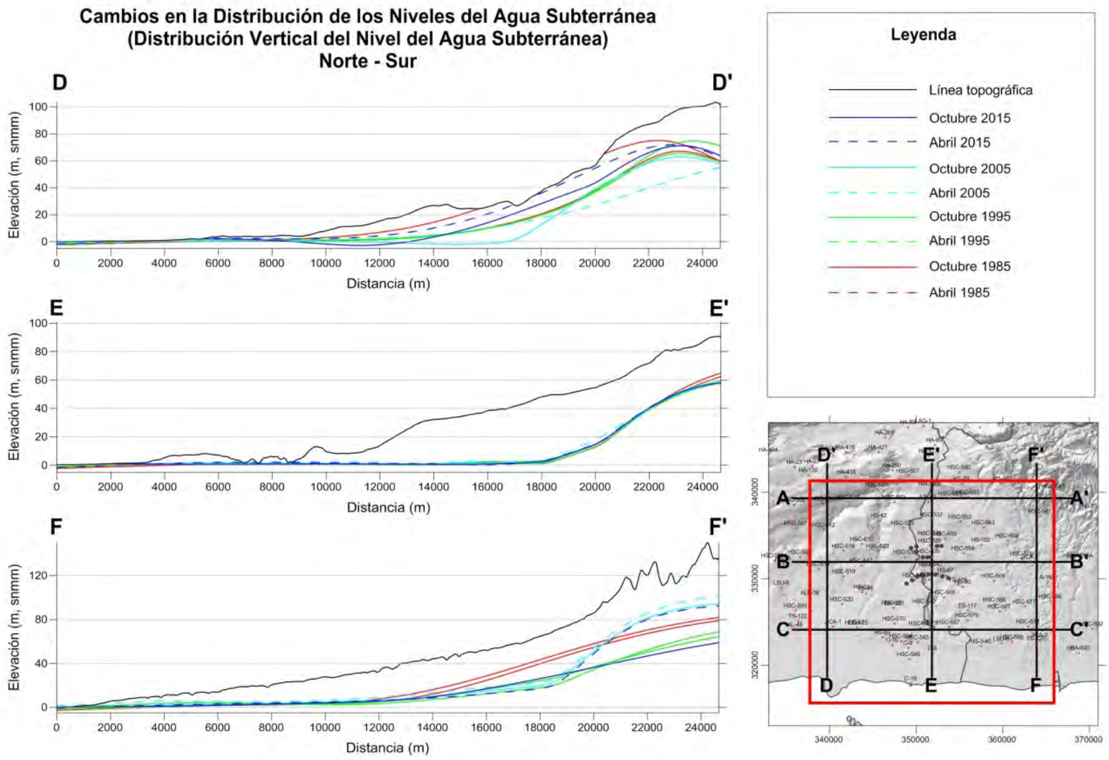

Figure 2-73: Changes in the groundwater level distribution (Vertical groundwater level distribution) North-South

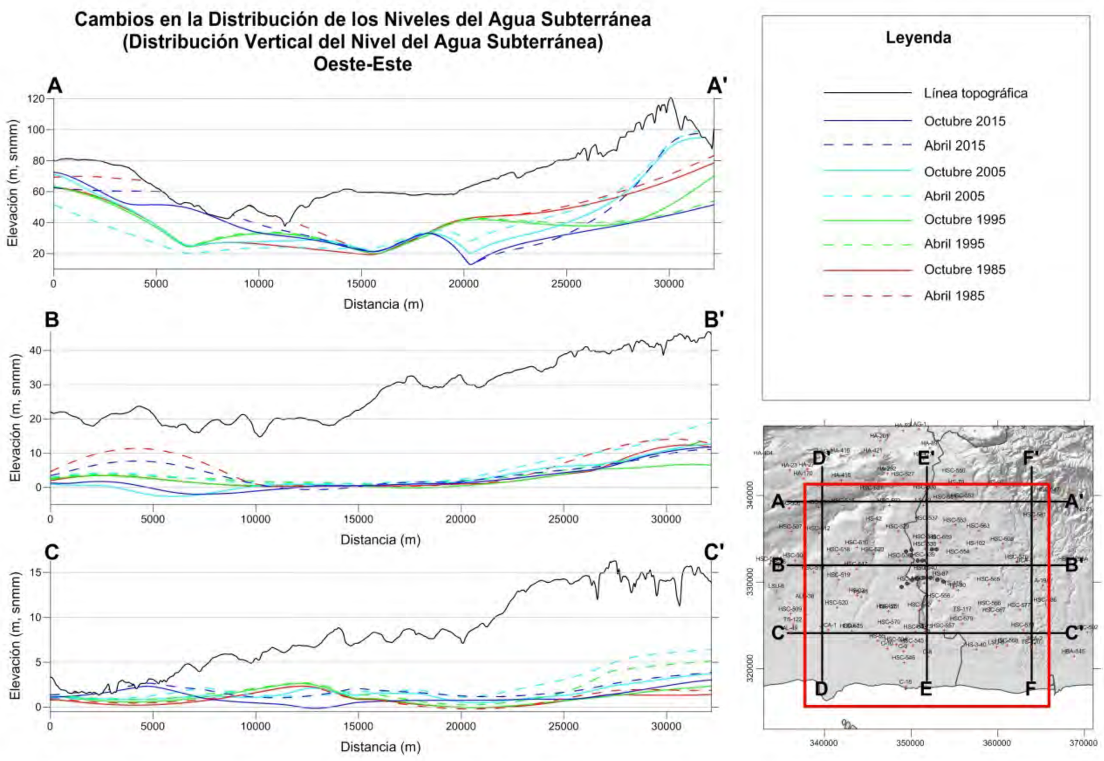

Figure 2-74: Changes in the groundwater level distribution (Vertical groundwater level distribution) West-East

2.5 Groundwater Quality

The groundwater quality in the studied sources of the provinces Artemisa and Mayabeque has been analyzed through the following scheme:

Water quality is influenced by:

- The dissolution of the rocks in the catchment area of the aquifer.
- The influence of the sea is paramount because the level of salts present will depend on it, mainly Sodium (Na) and Chlorine (Cl).

The quality of the water is influenced by the anthropic action, where the following intervene:

- The agricultural activity, which is manifested in the concentrations of fertilizers that are available in the soil to achieve crops and their surpluses, are infiltrated across the different strata and are also key parts in the runoff waters flowing into the surface waters that also recharge the water table through underground rivers and streams.
- Domestic activities, in which the man`s daily contribution is based on organic matter, detergents (Nitrogen (N) and Phosphorus (P) contributions) and other elements that have a negative influence on the water quality in high volumes and concentrations.
- Industrial activities, in this case the contribution is concentrated in the organic matter in high volumes and concentrations, as well as increase in the levels of heavy metals that are detrimental to health.

The Cuenca Sur aqueduct was built in the 1950s and it consists of 20 exploitation wells, with a depth of between 25 and 90 m, with a total extraction use of 3.02 m^3/s. From 1976 on, information was gathered in this aqueduct of the periodic controls of mineralization, exploitation and dynamic levels, where it can be observed that more than half of the wells pump below the mean sea level (2 to 6 m) and only 4 have a rise in Chlorides from 50 to 100 mg/l from 1985. The rest of the wells pump with dynamic levels above the mean sea level and half of them show a rise in Chlorides from 1985.

Agricultural and livestock enterprises of Güira de Melena, Quivicán, Alquízar, Batabanó and San Antonio de los Baños are the groundwater consumers for irrigation, and the total extraction is 2 m^3/s.

The rest of the users, among which are small aqueducts, have an extraction cost of 1.9 m^3/s.

a. Seawater intrusion

Hydrochemical conditions are homogeneous in general, in most of the area. Due to its chemical composition, bicarbonate-calcic waters predominate with a mineralization from 0.5 to 0.7 g L^{-1}. There are sudden changes on the hydrochemical environment towards the coastal area of the territory.

Throughout the coastal area, groundwater, with a total mineralization of up to 1 g L^{-1}, lies on the salinized waters of a chloride-sodium composition with dry residue up to 40 g L^{-1}.

Freshwater in the area is closely related to highly mineralized waters. The nature of this relationship has been broadly studied in accordance with the results of the systematic monitoring of salinity in the observation network wells. According to the observations gathered from the wells, with a hyper-annual series in the salinity measurements, the graphs of dependence of the lay depth of the groundwater total mineralization and its variation in time were created.

Based on the analysis of these observations it is possible to point out the following particularities in the behavior of the borders between the freshwater and saltwater:

- The existence of an area where there is practically no freshwater, which coincides with the swampy area and extends as a strip parallel to the coast, with a maximum width of 7 km and an area of 83 km^2. The boundary of the area is determined by the isolinea with salinity value equals to 1 g L^{-1} with elevation equals to zero.
- The contact surface between freshwater and saltwater has been established by the mineralization of 1 g L^{-1}. The surface is deepened towards the north of the basin with a gentle slope.
- The hyper-annual observations of the period from 1973 to 2015 show the existing balance in the area with mineralization from 20 to 30 g L^{-1}, regardless of the magnitude of the precipitations and the volume of the extraction.
- The thickness of the diffusion or transition area, with a mineralization of 1 to 30 g L^{-1}, varies from 10 a 15 m.
- The elevation of the diffusion area can be observed qualitatively, only in the region where the supply source of Cuenca Sur is located. However, this elevation has a local nature and has only been determined in the HSC-542 and HSC-541 wells.
- In general, a regional variation of the diffusion area over time is not observed. It is assumed that, in some cases, the presence of vertical karstic pipes facilitates the emergence of upward flows which, jointly with the extraction, cause the local suction of the saltwater without disturbing the interface balance in the influence area of the source. In order to keep a constant total volume of extraction in such cases, it is possible to seal the wells in which an increase in mineralization is observed or to replace them by new ones.

Figure 2-75: Temporal salinity behavior (1 g L^{-1}) in the HSC-542 well.

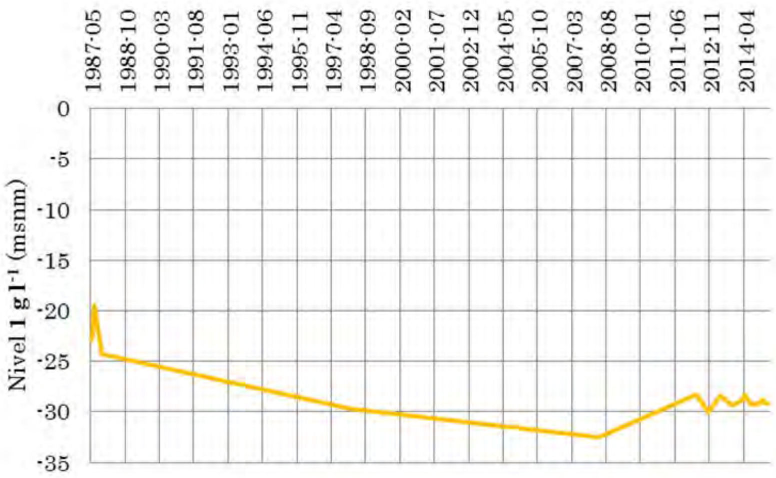

Figure 2-76: Temporal salinity behavior (1 g L^{-1}) in the HSC-541 well.

Figure 2-77: Temporal salinity behavior (1 g L^{-1}) in the HSC-540 well

- Where the diffusion area has a thickness of some tens of meters and the mineralization varies from 1 to 3 g/L, the dynamic balance is less stable and its displacement is possible under the influence of input and discharge.
- The surface of the diffusion area spreads from elevation 0, near the coastal strip, to absolute elevations of -30 to -40 mamsl above the sea level in the central area, in the form of an anomaly penetrating 14 km of the area. Towards the extremes, the diffusion area can exceed the altitude -140 mamsl, like, for example, near the hydrodynamic limit with the Batabanó section.

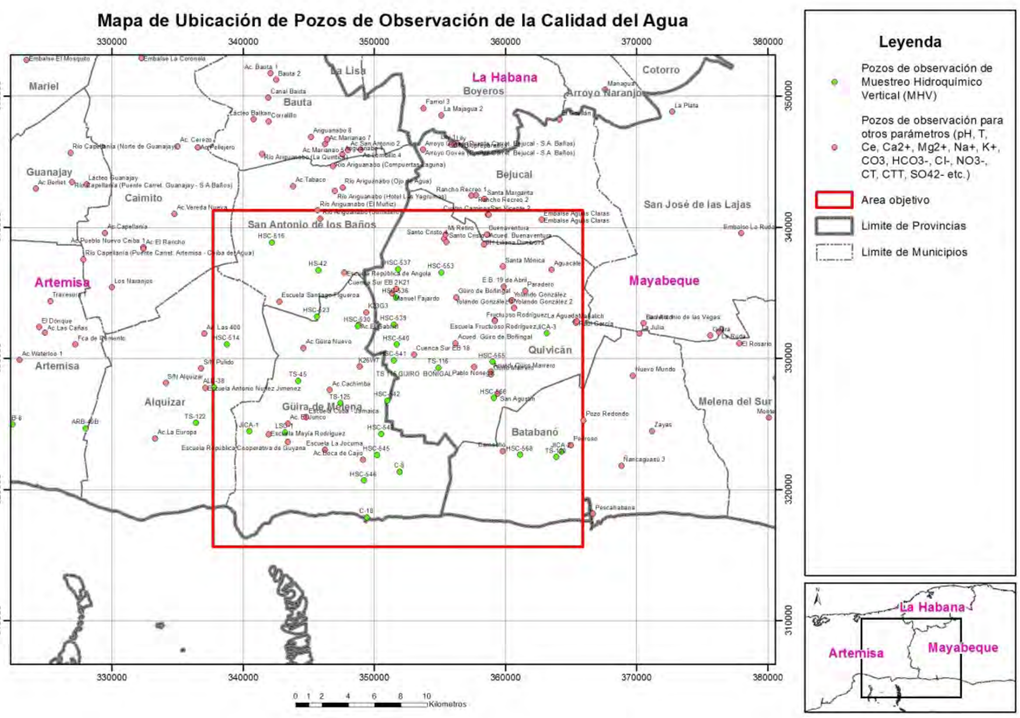

Figure 2-78: Map of the water quality observation wells

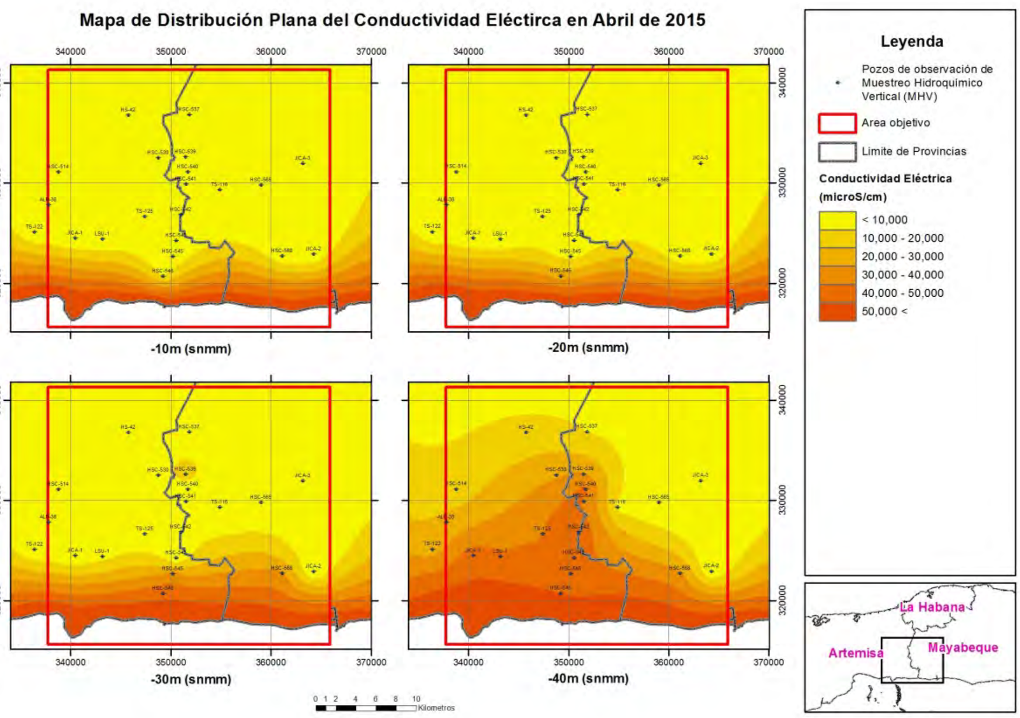

Figure 2-79: Distribution map of the electrical conductivity in April 2015

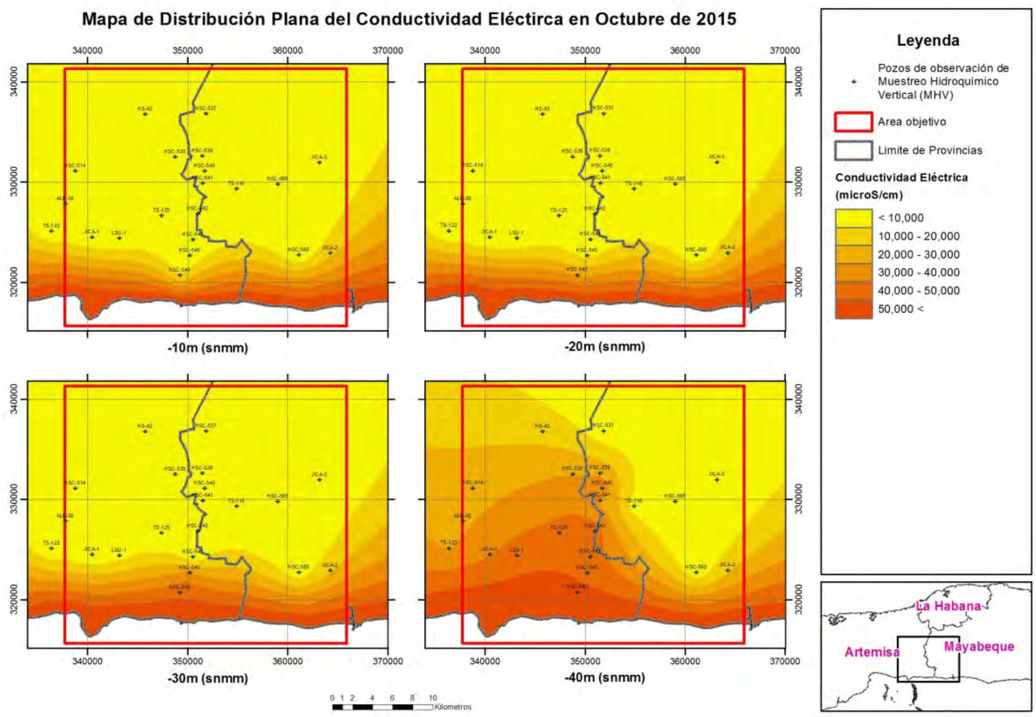

Figure 2-80: Distribution map of the electrical conductivity in October 2015

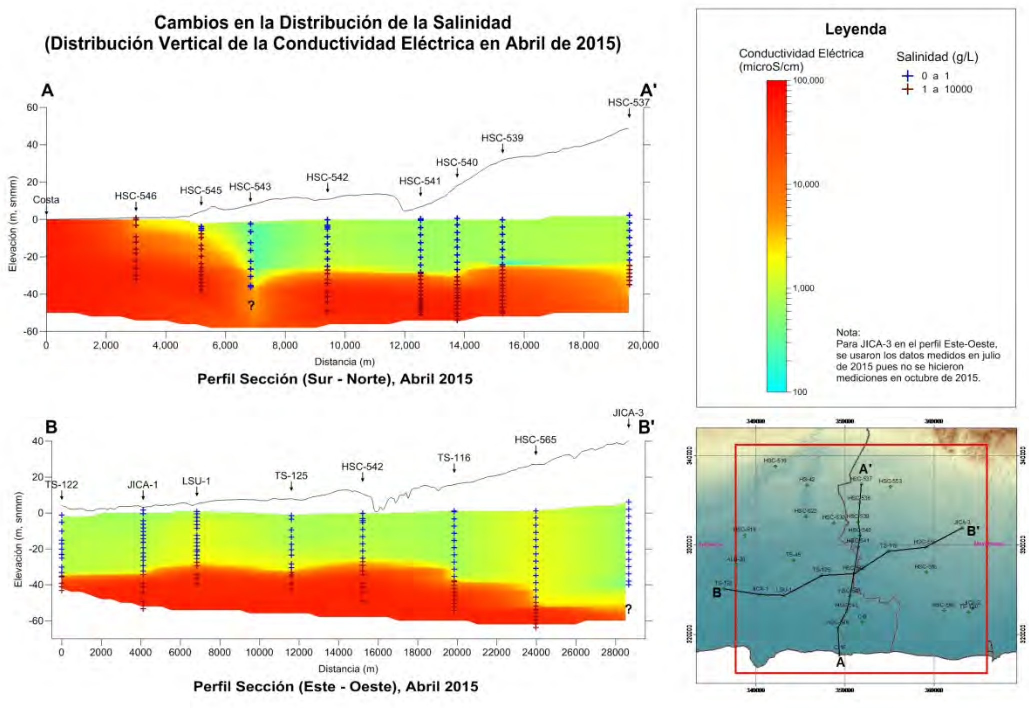

Figure 2-81: Changes in the salinity distribution (Vertical disruption of the electrical conductivity in April 2015)

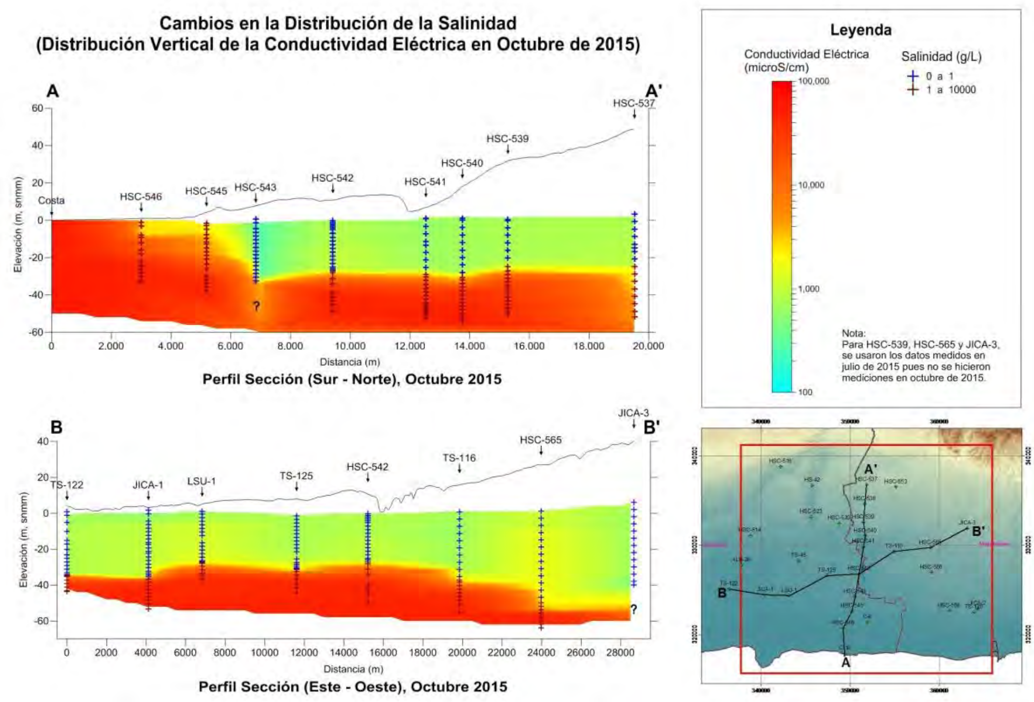

Figure 2-82: Changes in the salinity distribution (Vertical disruption of the electrical conductivity in October 2015)

b. Water quality monitoring network (REDCAL)

b.1 Elementos encontrados en estudios anteriores de calidad del agua subterránea

According to Norma Cubana, temperatura del agua, pH, nitrate ion (NO^{3-}), Chloride ion (Cl^-), sulfate ion (SO_4^{2-}), calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), Sodium ion (Na^+), potassium ion (K^+), Total dissolved solid (TDS), Total coliforms (TC), Thermotolerant coliforms (TTC) in the groundwater have been mesured. In addition, electric conductivity (EC) and bicarbonate ion (HCO_3^-) are also observing as significant parameters reflected from salinity and geological conditions. Furthermore, Chemical oxygen demand (COD) and biological oxygen demand (BOD) are monitoring as indicators of industrial pollutants.

b.2 Estimated groundwater current condition in the target area

The provinces involved in the JICA Project are Artemisa and Mayabeque, where several underground sources were selected that allowed to develop the studies and analyzes proposed by the Japanese experts. Each province made a selection, of which the main parameters obtained for the work are shown below (Table 2-11 and Table 2-12 for Artemisa and Mayabeque respectively).

Table 2-10: Wells of the water quality network to be monitored in the JICA project area

Basin	Initials	Initials	Name	x	y	MSMSL	Monthly Network	Semestral Network	MHV Network	Diameter	Depth	Condition
HS-3	A-19A		La Sonora	365200	329600	32.69	Yes	No	No	2	33	Bueno
HS-3	HS-102		Rosario	357900	334150	44.81	No	Yes	No	1.5	55	Bueno
HS-3	HS-87		San José	353450	330400	18.93	No	Yes	No	1.5	19	Bueno
HS-3	HS-90		La Caridad	355450	329050	17.51	No	Yes	No	1.5	17	Bueno
HS-3	HSC-536	TS-13	Soria	351700	335100	39.72	No	Yes	Yes	0.4	70	Bueno
HS-3	HSC-537	TS-6	Albertina	351850	336800	49.58	No	Yes	Yes	0.4	94	Bueno
HS-3	HSC-538	TS-14	Resecadora	351700	333850	35.26	No	Yes	No	0.3	70	Malo
HS-3	HSC-539	TS-3	Fajardo	351600	332750	32.18	No	Yes	Yes	0.3	86	Bueno
HS-3	HSC-540	TS-E2	El Punto	351800	331100	18.09	No	Yes	Yes	0.2	89	Bueno
HS-3	HSC-541	TS-7	Buffón	351500	329800	7.01	Yes	No	Yes	0.3	51	Bueno
HS-3	HSC-551		La Salud	353650	339250	58.04	No	Yes	No	0.3	38	Bueno
HS-3	HSC-552		El Cafetal	356025	339400	63.23	No	Yes	No	0.3	70	Bueno
HS-3	HSC-553		San Pantaleón	354900	336750	57.54	No	Yes	No	0.3	65	Bueno
HS-3	HSC-554		Güiro Boñingal	355550	332750	35.72	No	Yes	No	0.3	65	Bueno
HS-3	HSC-556		Rosario	353250	327850	14.90	No	Yes	No	0.3	22	Bueno
HS-3	HSC-557		Las Nieves	353750	324500	9.65	No	Yes	No	0.3	20	Bueno
HS-3	HSC-563		19 de Abril	357800	335800	51.99	Yes	No	No	0.3	61	Bueno
HS-3	HSC-565	TS-42	Güiro Marrero	359000	329700	27.57	No	Yes	Yes	0.3	100	Bueno
HS-3	HSC-566	TS-43	San Agustín	359400	327350	23.25	No	Yes	Yes	0.3	43	Malo
HS-3	HSC-567		Mortuorio	359650	326200	20.23	No	Yes	No	0.3	24	Bueno
HS-3	HSC-568	TS-44	Camacho	361160	322740	9.46	No	Yes	Yes	0.4	63	Malo
HS-3	HSC-576		La María	362150	332350	42.45	No	Yes	Yes	0.3	49	Bueno
HS-3	HSC-577		Covarrubias	362550	326750	21.28	No	Yes	No	0.3	20	Bueno
HS-3	HSC-578		Santa Lucía	363060	334350	16.49	No	Yes	No	0.3	0	Bueno
HS-3	HSC-579		Cuba 9	355900	325200	8.69	No	Yes	No	0.3	22	Malo
HS-3	HSC-581		Penal Quivicán	364350	337200	70.20	No	Yes	No	0.3	56	Bueno
HS-4	HSC-586		Apeadero	365750	326800	26.47	Yes	No	No	0.3	31	Bueno
HS-3	HSC-608		Los Dátiles	360600	334400	51.55	No	Yes	No	0.3	50	Bueno
HS-3	HSC-609		La Capa	353600	334700	42.81	No	Yes	No	0.3	51	Bueno
HS-3	LSU-3		La Salud	351480	338890	56.66	Yes	No	No	0.5	46	Malo
HS-3	LSU-8		Camacho	359900	322550	8.55	Yes	No	No	0.5	21	Bueno
HS-3	TS-116	TS-116	Güiro Boñingal	354900	329300	16.52	No	Yes	Yes	0.4	72	Bueno
HS-3	TS-117	TS-117	Pablo Noriega	356000	326300	15.64	No	Yes	Yes	0.3	0	Malo
HS-4	TS-120	TS-120	Pedroso	363800	322200	9.76	No	Yes	Yes	0.11	8	Malo

Table 2-11: Underground sources directly involved in the JICA Project, Artemisa province

Listados de estaciones del Proyecto JICA de la REDCAL - ARTEMISA											
No.	Provincia	Cuenca Subterrànea	Nombre de la estación	Municpio	X	Y	Tipo de agua	Tipo de estación	Frecuencia de muestreo	Uso	Determinaciones
1	Artemisa	HS-3	Ac. Waterioo 1	Artemisa	322950	329900	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, Co_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
2	Artemisa	HS-3	Ac. Las 400	Alquizar	337050	331900	Subterránea	Vigilancia	Semestral	Fuente para riego agricola	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4, DBO_5, DQO
3	Artemisa	HS-3	Ac. La Europa	Alquizar	333300	323900	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
4	Artemisa	HS-3	S/N Pulido	Alquizar	336800	329250	Subterránea	Básica	Semestral	Fuente para consumo	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3,

										humano	CT, CTT, SO_4
5	Artemisa	HS-2	Ac. El pilar	Artemisa	320170	334250	Subterránea	Básica	Semestral	Fuente para abasto industrial	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
6	Artemisa	HS-2	Ac. La Matilde	Artemisa	319380	332110	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
7	Artemisa	HS-3	Ac. El Favorito	Artemisa	321900	332900	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
8	Artemisa	HS-3	Ac. Güira Nuevo	Guira de Melena	344600	330800	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
9	Artemisa	HS-3	Ac. Cachimba	Güira de Melena	346600	327600	Subterránea	Vigilancia	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
10	Artemisa	HS-3	Ac. Boca de Cajio	Güira de Melena	349150	322300	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
11	Artemisa	HS-3	Ac. Vereda Nueva	Caimito	334770	341050	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
12	Artemisa	HS-3	Ac. Pueblo Nuevo Ceiba 1	Caimito	332400	338500	Subterránea	Básica	Semestral	Fuente para riego agricola	pH, T, CE, Na, Ca, Mg, CO_3, HCO_3
13	Artemisa	HS-3	K26W7	Güira de Melena	348900	329400	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
14	Artemisa	HS-3	K23G3	Güira de Melena	349375	333525	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
15	Artemisa	HS-3	Ac. El Gabriel	Güira de Melena	348800	332600	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
16	Artemisa	HS-3	Escuela La Jocuma	Güira de Melena	346250	323050	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
17	Artemisa	HS-3	El Donque	Artemisa	324450	332400	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4

Table 2-12: Underground sources directly involved in the JICA Project, Mayabeque province (Horizontal monitoring)

Listados de estaciones del Proyecto JICA de la REDCAL - MAYABEQUE											
No.	**Provincia**	**Cuenca Subterrànea**	**Nombre de la estación**	**Municpio**	**X**	**Y**	**Tipo de agua**	**Tipo de estación**	**Frecuencia de muestreo**	**Uso**	**Determinaciones**
1	Mayabeque	HS-3	Aguacate	Quivicán	363530	336780	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, Co_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
2	Mayabeque	HAV-1	Arroyo Govea (Puente Carret, Bejucal –S.A. Baños)	Bejucal	353700	345925	Subterránea	Vigilancia	Semestral	Fuente para riego agricola	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4, DBO_5, DQO
3	Mayabeque	HS-3	Buenaventura	Bejucal	358568	339470	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
4	Mayabeque	HS-3	Camacho	Batabanó	359800	322940	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
5	Mayabeque	HAV-1	CN Biopreparados	Bejucal	355854	346322	Subterránea	Básica	Semestral	Fuente para abasto industrial	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
6	Mayabeque	HS-3	Cuatro Caminos	Quivicán	358724	340972	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
7	Mayabeque	HS-3	Cuenca Sur EB 18	Quivicán	353039	330307	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
8	Mayabeque	HS-3	Cuenca Sur EB 2	Quivicán	351670	335320	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
9	Mayabeque	HS-3	Fructuoso Rodriguez	Quivicán	359187	332863	Subterránea	Vigilancia	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
10	Mayabeque	HS-3	Güiro de Boñingal	Quivicán	356243	334688	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
11	Mayabeque	HS-3	Güiro Marrero	Quivicán	358912	328813	Subterránea	Básica	Semestral	Fuente para consumo	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl,

										humano	NO_3, CT, CTT, SO_4
12	Mayabeque	HS-3	IIH Liliana Dimitrova	Quivicán	358368	338721	Subterránea	Básica	Semestral	Fuente para riego agricola	pH, T, CE, Na, Ca, Mg, CO_3, HCO_3
13	Mayabeque	HAV-1	Lily	Bejucal	356058	346322	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
14	Mayabeque	HS-3	Manuel Fajardo	Quivicán	351355	334976	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
15	Mayabeque	HS-3	Mi Retiro	Quivicán	355440	339466	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
16	Mayabeque	HS-3	Ñancaguasú 3	Batabanó	368850	321830	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
17	Mayabeque	HS-3	Pablo Noriega	Quivicán	357618	329362	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
18	Mayabeque	HS-3	Paradero	Quivicán	361506	335170	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
19	Mayabeque	HS-4	Pedroso	Batabanó	365000	323400	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
20	Mayabeque	HS-4	Pescahbana	Batabanó	366650	318160	Subterránea	Básica	Semestral	Fuente para abasto industrial	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
21	Mayabeque	HS-4	Pozo Redondo	Batabanó	365950	325300	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
22	Mayabeque	HS-3	Rancho Recreo 1	Bejucal	357413	342425	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
23	Mayabeque	HAV-1	Rancho Recreo 2	Bejucal	357751	342465	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
24	Mayabeque	HS-3	Raúl Garcia	Quivicán	365436	332855	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
25	Mayabeque	HS-3	San Agustin	Quivicán	359418	327325	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
26	Mayabeque	HS-4	San Vicente 2	Batabanó	358655	340985	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
27	Mayabeque	HS-3	Santa Margarita	Bejucal	358408	342172	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
28	Mayabeque	HS-3	Santa Mónica	Quivicán	359786	337012	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
29	Mayabeque	HS-3	Santa Cristo	Quivicán	355497	338893	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
30	Mayabeque	HS-3	Yolando González 1	Quivicán	360640	333874	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
31	Mayabeque	HS-3	Yolando González	Quivicán	360521	334467	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4
32	Mayabeque	HS-4	Zayas	Batabanó	371177	324473	Subterránea	Básica	Semestral	Fuente para consumo humano	pH, T, Ca, Mg, Na, K, CO_3, HCO_3, Cl, NO_3, CT, CTT, SO_4

b.3 Characteristics of the groundwater quality in the study area

In the information obtained from the REDCAL stations that are part of the JICA Project, the laboratory data of the samples belonging to the years prior to the Project’s development were analyzed and the results for the years 2013 to 2015 were included. Results also analyzed the most significant statisticians, Mean, Standard Deviation, Median, Minimum Value and Maximum Value. Of them, ç each station can consider as objective conservation values those obtained by the median value.

It can determine for example: the maximum values recorded in the Chlorine (Cl) and Sodium (Na) elements where the seawater intrusion alert is located. Climate change may be involved with its progression in time and/or an overexploitation of the wells involved in a given aquifer. It is also important to include in this type of analysis the extreme values of the electrical conductivity (mS/m).

b.4 Distribution of the concentration of each element studied in the water quality (horizontal)

Artemisa

In the distribution of the analyzed elements it has been observed that in the majority of the stations corresponding to the karstic nature of the area the anions and cations behave in the following order: Bicarbonate (HCO_3) as a priority element, shared with Calcium (Ca). However, there are stations such as the Jocuma School which show an increase in Chloride (Cl) and Sulfate (SO_4), apparently in the times of the year where hurricanes manifest with greater intensity, thus increasing the seawater intrusion in the coastal area or its surroundings.

Mayabeque

As in Artemisa, the karstic nature is imposed denoting the prevalence of Bicarbonate (HCO_3) and Calcium (Ca) with less alteration due to the Chlorine (Cl) and Sodium (Na) ions, and the stations involved are: Camacho, Cuenca Sur UB-18, Fructuoso Rodríguez, Güiro Boñigal, Güiro Marrero, Havana Fishing Enterprise, Pozo Redondo and San Agustín. In the case of this province and the wells used for the JICA Project, it has been observed that there is a higher quantity of these wells that are affected to some extent in certain seasons of the year, which could coincide with hurricane seasons and/or increased of the concentrations resulting from over-exploitation of aquifer waters and having exceeded the critical level where seawater intrusion becomes more evident and leads to a greater impact on the water quality.

Table 2-13: Distribution of the concentration of the elements in the underground stations studied, Artemisa province, water quality (Horizontal-monitoring)

Estaciones	Estadigrafo	Period Años	T (ºC)	CE ms/m	pH U	NO_3^{-1} mgL^{-1}	CO_3^{-2} mgL^{-1}	HCO_3^{-1} mgL^{-1}	Cl^{-1} mgL^{-1}	SO_4^{-1} mgL^{-1}	Ca^{+2} mgL^{-1}	Mg^{+2} mgL^{-1}	Na^{+1} mgL^{-1}	K^{+1} mgL^{-1}	SDT mgL^{-1}
Waterloo-1	Media	2006-2015	23,3	75,3	7,37	12	0	343	52	24	116	10	34	2,0	590
	Desv-Est		1,3	3,7	0,32	6	0	17	9	6	4	2	6	0,2	15
	Mediana		23,2	76,0	7,29	13	0	342	53	25	116	10	34	2,0	593
	Minimo		20,8	66,0	7,08	1	0	305	32	12	110	5	28	1,8	560
	Máximo		26,1	80,2	8,40	19	0	366	69	31	124	13	43	2,4	609
Ac. Las 400 (HS-3)	Media	2006-2014	23,3	66,1	7,25	30	0	305	31	22	108	8	18	2,8	520
	Desv-Est		2,1	2,0	0,15	8	0	10	7	3	6	2	2	0,3	24
	Mediana		23,1	66,0	7,23	30	0	304	34	22	108	8	19	2,9	521
	Minimo		20,5	63,6	7,05	21	0	293	21	18	100	6	15	2,4	470
	Máximo		26,0	69,0	7,55	42	0	323	39	25	120	12	20	3,0	554
Ac. La Europa (HS-3)	Media	2006-2015	22,5	67,0	7,35	27	0	0	97	0	0	0	63	0,0	
	Desv-Est		0,7		0,16	11	0	0	31	0	0	0	0	0,0	
	Mediana		22,5	67,0	7,35	27	0	0	113	0	0	0	63	0,0	
	Minimo		22,0	67,0	7,23	19	0	0	61	0	0	0	63	0,0	
	Máximo		23,0	67,0	7,46	35	0	0	117	0	0	0	63	0,0	
S/N Pulido (HS-3)	Media	2015	23,9	65,7	7,52	35	0	226	36	0	98	8	18	2,4	431
	Desv-Est		0,1	3,3	0,10	1	0	0	15	0	0	0	4	0,0	1
	Mediana		23,9	65,7	7,52	35	0	226	36	0	98	8	18	2,4	431
	Minimo		23,8	63,3	7,45	34	0	226	25	0	98	8	15	2,4	431
	Máximo		24,0	68,0	7,59	36	0	226	46	0	98	8	21	2,4	431
Ac. El Pilar (HS-2)	Media	2006-2015	24,5	66,8	7,31	41	0	0	30	32	0	0	0	0,0	
	Desv-Est		1,3	2,8	0,28	4	0	0	2	0	0	0	0	0,0	
	Mediana		24,5	66,5	7,24	41	0	0	32	32	0	0	0	0,0	
	Minimo		23,6	64,0	7,02	35	0	0	28	32	0	0	0	0,0	
	Máximo		25,4	70,0	7,71	45	0	0	32	32	0	0	0	0,0	
Ac. La Matilde (HS-2)	Media	2006-2015	23,8	78,7	7,15	30	0	380	38	27	123	11	25	4,7	629
	Desv-Est		1,3	5,9	0,19	9	0	51	7	6	20	2	6	1,4	89
	Mediana		23,7	80,0	7,12	33	0	403	39	27	131	10	27	5,2	669
	Minimo		22,1	64,8	6,92	7	0	281	15	17	87	9	10	1,1	449
	Máximo		26,0	85,0	7,73	38	0	415	44	35	145	16	28	5,5	697

Ac. El Favorito (HS-3)	Media	2006-2015	24,2	64,9	7,36	15	0	329	26	0	110	6	17	3,0	501
	Desv-Est		2,2	6,5	0,20	3	0	0	2	0	0	0	0	0,0	0
	Mediana		22,8	63,0	7,38	15	0	329	25	0	110	6	17	3,0	501
	Minimo		20,0	59,0	7,11	11	0	329	25	0	110	6	17	3,0	501
	Máximo		27,9	76,0	7,65	21	0	329	28	0	110	6	17	3,0	501
Ac. Güira Nuevo (HS-3)	Media	2006-2015	23,1	77,4	7,35	37	0	298	58	34	111	11	32	5,3	574
	Desv-Est		2,2	6,4	0,15	11	0	55	16	7	13	5	6	8,2	92
	Mediana		22,8	79,2	7,33	38	0	311	59	35	116	10	31	3,8	606
	Minimo		20,0	58,6	7,12	0	0	88	25	17	82	2	20	1,8	315
	Máximo		27,9	88,1	7,59	58	0	366	97	46	132	29	40	42,9	710
Ac. Cachimba (HS-3)	Media	2006-2015	23,0	83,9	7,41	37	0	283	75	45	102	14	44	3,7	584
	Desv-Est		2,1	9,4	0,12	9	0	67	31	13	13	6	14	0,6	105
	Mediana		22,6	85,5	7,39	40	0	295	74	48	103	16	45	3,9	611
	Minimo		19,2	63,3	7,25	16	0	83	7	21	77	2	23	2,4	267
	Máximo		25,8	106,7	7,61	52	0	360	150	65	122	23	78	4,6	732
Ac. Boca de Cajio (HS-3)	Media	2006-2015	24,4	125,2	7,35	37	0	258	312	75	110	22	146	6,0	941
	Desv-Est		1,1	94,1	0,12	6	0	71	117	44	23	19	93	4,2	446
	Mediana		24,8	150,0	7,32	40	0	258	340	75	110	22	146	6,0	941
	Minimo		23,2	0,0	7,25	30	0	207	150	44	94	8	80	3,0	626
	Máximo		25,2	201,0	7,49	42	0	308	419	106	126	35	212	8,9	1257
Ac. Vereda Nueva (HS-3)	Media	2006-2015	22,8	77,3	7,16	64	0	351	24	24	128	7	14	7,4	612
	Desv-Est		2,5	10,0	0,19	43	0	60	9	9	22	6	11	5,5	88
	Mediana		22,3	75,2	7,16	44	0	342	22	20	130	5	11	5,9	584
	Minimo		19,7	66,7	6,69	16	0	238	15	15	83	1	6	3,3	518
	Máximo		27,2	103,1	7,52	153	0	451	50	45	156	22	45	22,5	771
Ac. Pueblo Nuevo Ceiba 1 (HS-3)	Media	2006-2015	22,4	73,3	7,31	30	0	335	40	25	117	9	21	2,9	572
	Desv-Est		1,9	9,0	0,20	16	0	67	36	17	16	4	20	1,2	93
	Mediana		22,4	70,9	7,29	30	0	351	25	17	119	8	13	3,1	594
	Minimo		19,5	64,0	7,00	5	0	201	14	3	80	3	10	0,9	387
	Máximo		25,4	97,5	7,61	50	0	409	133	49	132	17	68	4,6	706
K26W7 (HS-3)	Media	2007-2015	23,3	87,7	7,62	32	0	297	86	37	105	14	50	3,7	616
	Desv-Est		2,1	14,1	0,25	15	0	37	35	12	13	7	19	0,8	88
	Mediana		23,4	90,7	7,72	32	0	311	90	41	110	13	55	3,8	611
	Minimo		18,4	62,7	7,09	0	0	128	18	14	54	1	12	1,1	366
	Máximo		27,5	118,9	7,98	58	0	354	163	63	128	39	91	5,2	767
K23G3 (HS-3)	Media	2007-2015	23,3	84,5	7,59	26	0	287	78	32	109	12	45	4,3	588
	Desv-Est		2,0	18,3	0,26	15	0	61	47	23	13	6	28	6,6	114
	Mediana		23,4	81,0	7,61	25	0	302	71	26	110	11	38	3,0	578
	Minimo		19,8	62,1	7,10	0	0	18	14	7	57	1	12	2,1	365
	Máximo		27,2	137,1	8,52	52	0	366	227	169	128	35	126	50,0	907
Ac. El Gabriel (HS-3)	Media	2007-2015	23,4	96,0	7,38	34	0	268	123	41	111	15	61	3,2	656
	Desv-Est		2,0	18,2	0,10	11	0	70	53	9	14	4	28	0,3	99
	Mediana		24,0	103,7	7,39	34	0	296	128	42	110	16	76	3,2	649
	Minimo		20,7	65,1	7,27	11	0	120	32	22	88	8	16	2,7	525
	Máximo		25,3	117,5	7,55	46	0	323	202	51	131	19	88	3,6	834
Escuela La Jocuma (HS-3)	Media	2007-2015	22,7	180,2	7,55	46	0	303	310	108	95	36	206	12,6	987
	Desv-Est		2,4	77,2	0,21	12	0	62	208	132	34	19	140	9,4	420
	Mediana		22,3	178,2	7,57	40	0	305	307	90	92	36	241	16,9	1124
	Minimo		19,4	75,1	7,15	36	0	129	21	8	12	10	17	1,3	280
	Máximo		27,4	370,0	7,77	70	0	390	709	528	160	72	428	29,7	1720
El Donque (HS-3)	Media	2009-2015	22,6	57,2	7,52	29	0	259	25	15	99	7	10	2,2	441
	Desv-Est		1,9	4,5	0,18	14	0	22	3	5	10	5	1	0,9	33
	Mediana		23,1	58,4	7,56	29	0	258	25	14	100	5	10	2,4	439
	Minimo		18,7	51,2	7,28	12	0	225	20	10	86	2	8	0,8	395
	Máximo		25,6	64,2	7,77	51	0	305	30	23	112	15	13	3,6	494
Ac. El Vivero (HS-3)	Media	2014-2015	24,1	63,9	7,19	15	0	348	18	15	108	9	12	1,3	527
	Desv-Est		1,6	6,2	0,10	7	0	26	6	6	10	2	6	1,3	35
	Mediana		24,1	61,7	7,23	15	0	360	18	15	110	10	10	0,9	536
	Minimo		21,8	60,7	7,00	5	0	287	14	10	83	7	9	0,8	440
	Máximo		26,1	81,0	7,32	34	0	372	39	30	116	12	28	4,9	575
Ac. Toledo (HS-3)	Media	2014-2015	24,1	59,2	7,26	8	0	323	17	15	97	12	11	1,1	486
	Desv-Est		1,4	7,3	0,16	6	0	44	2	2	14	3	3	0,2	64
	Mediana		23,9	62,4	7,21	8	0	336	18	15	102	12	11	0,9	499
	Minimo		21,8	40,3	7,05	1	0	232	14	11	66	8	5	0,9	356
	Máximo		25,6	62,6	7,57	19	0	366	20	18	110	17	14	1,5	554
Ac. Quebrada (HS-3)	Media	2014	24,5	55,0	7,58	1	0	299	19	25	92	7	17	0,8	460
	Desv-Est		2,0	0,6	0,11	0	0	8	1	4	1	0	1	0,1	5
	Mediana		24,5	55,0	7,58	1	0	299	19	25	92	7	17	0,8	460
	Minimo		23,1	54,5	7,50	1	0	293	18	22	91	7	16	0,7	457
	Máximo		25,9	55,4	7,65	1	0	305	20	28	93	7	17	0,9	464

Table 2-14: Distribution of the concentration of the elements in the underground stations studied, Mayabeque province, water quality (Horizontal-monitoring)

Estaciones	Estadigrafo	Period Años	T (ºC)	CE ms/m	pH U	NO_3^{-1} mgL^{-1}	CO_3^{-2} mgL^{-1}	HCO_3^{-1} mgL^{-1}	Cl^{-1} mgL^{-1}	SO_4^{-1} mgL^{-1}	Ca^{+2} mgL^{-1}	Mg^{+2} mgL^{-1}	Na^{+1} mgL^{-1}	K^{+1} mgL^{-1}	SDT mgL^{-1}	CT NMP $100mL^{-1}$	CTT NMP $100mL^{-1}$
Aguacate	Media	2014-2015	24,3	71,0	7,23	9	0	365	26	21	83	32	16	1,2	571	12,3	2,0
	Desv-Est		0,9	2,1	0,14	5	0	41	5	12	17	6	7	0,4	56	20,5	0,0
	Mediana		24,4	71,2	7,20	11	0	385	26	19	81	32	18	1,0	580	2,0	2,0
	Minimo		23,1	68,3	7,11	1	0	336	21	9	66	24	6	0,9	498	2,0	2,0
	Máximo		25,2	73,4	7,43	11	0	433	30	37	104	39	20	1,8	626	43,0	2,0
Buena Ventura	Media	2013-2015	23,1	66,7	7,27	26	0	342	22	12	116	9	12	1,3	539	12,0	3,0
	Desv-Est		2,7	6,3	0,25	18	0	21	6	5	15	3	6	0,4	57	13,9	2,0
	Mediana		23,7	68,7	7,21	35	0	348	25	11	124	8	13	1,1	567	2,0	2,0
	Minimo		18,8	56,4	7,10	2	0	305	14	5	98	4	2	0,9	448	2,0	2,0
	Máximo		26,0	72,6	7,70	43	0	354	28	19	130	13	17	1,8	582	30,0	6,0
Camacho	Media	2014-2015	24,4	891,5	7,21	19	0	359	91	28	98	23	52	3,2	665	2,0	2,0
	Desv-Est		2,6	24,9	0,12	5	0	12	6	7	3	3	6	0,2	21	0,0	0,0
	Mediana		25,3	893,0	7,20	20	0	360	92	29	99	23	53	3,3	662	2,0	2,0
	Minimo		20,6	860,0	7,10	12	0	342	84	21	94	19	44	3,0	648	2,0	2,0
	Máximo		26,3	920,0	7,36	23	0	372	97	35	101	25	59	3,3	689	2,0	2,0
CN-Biopreparados	Media	2013-2015	24,4	67,6	7,08	18	0	354	28	27	126	5	12	1,2	570	6,4	2,3
	Desv-Est		0,8	4,7	0,09	10	0	33	5	17	9	1	5	0,2	54	8,4	0,7
	Mediana		24,7	67,1	7,09	15	0	351	28	21	126	5	13	1,2	555	2,0	2,0
	Minimo		23,2	63,1	6,97	8	0	305	21	14	116	3	3	0,9	518	2,0	2,0
	Máximo		25,1	73,9	7,18	31	0	397	35	60	140	7	17	1,4	644	23,0	3,6
Cuatro Caminos	Media	2013-2015	23,7	61,0	7,05	18	0	334	17	20	111	5	8	1,1	515	2,3	2,3
	Desv-Est		2,0	5,8	0,21	14	0	57	5	19	17	3	4	0,4	93	0,7	0,7
	Mediana		23,9	58,5	7,16	17	0	348	15	10	117	4	8	0,9	558	2,0	2,0
	Minimo		20,7	56,6	6,70	1	0	238	14	5	82	2	2	0,9	367	2,0	2,0
	Máximo		26,2	70,5	7,20	41	0	384	25	53	127	10	13	1,8	599	3,6	3,6
Cuenca Sur UB-2	Media	2009-2015	24,1	62,7	7,38	16	0	330	29	21	101	11	17	2,6	528	62,0	3,7
	Desv-Est		1,8	10,0	0,24	8	0	56	12	7	9	6	6	1,6	57	244,1	6,0
	Mediana		24,2	63,6	7,32	16	0	314	25	19	104	12	17	1,9	528	2,0	2,0
	Minimo		20,2	6,6	6,93	1	0	220	16	4	76	1	6	0,3	377	2,0	2,0
	Máximo		27,8	85,8	7,85	42	0	636	69	38	118	42	40	5,1	832	1660,0	34,0
Cuenca Sur UB-18	Media	2012-2015	23,8	63,9	7,27	15	0	323	30	18	99	13	19	1,5	519	744,4	89,8
	Desv-Est		1,9	11,7	0,16	7	0	62	21	7	8	6	10	0,6	64	3842,2	357,4
	Mediana		23,7	65,9	7,23	14	0	354	20	17	101	13	16	1,4	540	2,0	2,0
	Minimo		20,0	6,7	6,99	1	0	37	15	11	74	2	5	0,3	231	2,0	2,0
	Máximo		27,6	87,6	7,69	38	0	390	110	51	112	36	55	3,3	589	24000,0	1600,0
Fructuoso Rguez	Media	2011-2015	23,4	67,5	7,35	16	0	326	28	23	103	10	18	2,0	526	12,0	4,0
	Desv-Est		2,3	5,7	0,19	10	0	42	18	16	10	5	11	1,3	70	15,6	3,5
	Mediana		23,9	66,9	7,31	17	0	314	25	20	105	12	17	1,8	527	4,0	2,0
	Minimo		18,7	59,4	7,10	1	0	248	2	6	78	3	6	0,9	427	2,0	2,0
	Máximo		26,8	80,9	7,65	30	0	368	71	64	112	17	45	4,9	673	30,0	8,0
Guiro Boñigal	Media	2013-2015	23,2	64,2	7,30	21	0	288	39	24	92	13	18	1,8	497	9,4	5,8
	Desv-Est		2,2	8,7	0,37	11	0	64	20	22	13	12	16	0,8	103	13,4	8,5
	Mediana		23,1	63,0	7,33	16	0	299	34	15	90	8	11	1,8	489	2,0	2,0
	Minimo		20,2	57,1	6,80	12	0	183	20	10	78	4	6	0,9	373	2,0	2,0
	Máximo		26,4	78,7	7,82	38	0	354	71	62	107	33	45	3,0	657	33,0	21,0
Guiro Marrero	Media	2013-2015	22,8	94,3	7,25	17	0	328	103	33	102	20	54	3,0	660	17,3	3,7
	Desv-Est		3,4	8,0	0.05	6	0	56	21	5	7	3	15	1,3	78	19,2	2,9
	Mediana		22,9	97,8	7,23	20	0	351	113	32	105	21	55	3,6	674	12,5	2,0
	Minimo		18,5	82,4	7,20	8	0	244	71	29	92	16	38	1,0	567	2,0	2,0
	Máximo		26,7	99,2	7,32	22	0	366	113	39	106	22	70	3,9	725	42,0	7,0
ITH-Lil. Dimitrova	Media	2013-2015	24,3	53,2	7,29	0	0	317	0	0	111	7	11	3,8	450		
	Desv-Est		1,2	27,2	0,26	0	0	49	0	0	22	8	4	5,7	71		
	Mediana		24,1	60,1	7,21	0	0	333	0	0	120	4	12	1,4	473		
	Minimo		22,5	0,0	7,00	0	0	226	0	0	84	2	3	1,1	318		
	Máximo		26,0	75,9	7,63	0	0	354	0	0	131	24	15	14,0	502		
Lily	Media	2013-2015	24,4	66,1	7,02	20	0	325	23	0	121	5	11	1,0	505	2,9	2,0
	Desv-Est		0,9	2,7	0,22	8	0	45	4	0	6	2	5	0,1	58	2,1	0,0
	Mediana		24,2	65,6	7,13	19	0	345	21	0	121	4	11	0,9	525	2,0	2,0
	Minimo		23,2	63,4	6,70	10	0	242	20	0	109	2	3	0,9	410	2,0	2,0
	Máximo		25,9	71,0	7,22	34	0	360	30	0	126	9	19	1,2	571	7,2	2,0
Manuel Fajardo	Media	2013-2015	23,9	59,6	7,43	20	0	275	27	17	98	6	9	2,3	453	12,8	2,0
	Desv-Est		1,2	4,0	0,19	7	0	62	11	7	13	2	2	1,6	56	20,2	0,0
	Mediana		23,9	57,8	7,45	19	0	299	23	18	102	7	10	2,1	477	3,0	2,0
	Minimo		22,4	57,4	7,18	12	0	183	18	8	80	3	6	0,9	368	2,0	2,0
	Máximo		25,3	65,6	7,63	28	0	317	43	23	108	7	11	4,3	487	43,0	2,0
Mi Retiro	Media	2013-2015	24,1	58,4	7,33	30	0	264	17	24	98	4	7	2,5	447	7,3	2,0
	Desv-Est		1,4	1,1	0,19	5	0	24	3	16	10	1	2	0,7	52	10,5	0,0
	Mediana		24,0	58,2	7,36	30	0	269	17	18	100	4	8	2,7	446	2,0	2,0
	Minimo		22,5	57,5	7,08	25	0	232	15	13	86	4	3	1,4	386	2,0	2,0
	Máximo		25,8	59,8	7,51	36	0	287	21	48	108	5	8	3,0	508	23,0	2,0
Ñancaguasu -3	Media	2014-2015	23,5	71,9	7,34	17	0	371	30	33	82	32	20	1,3	585	2,5	2,0
	Desv-Est		2,1	2,5	0,12	8	0	17	7	9	8	2	6	0,4	36	1,0	0,0
	Mediana		23,9	71,6	7,35	16	0	369	31	37	83	32	20	1,1	580	2,0	2,0
	Minimo		20,6	69,3	7,20	9	0	354	20	20	72	29	13	1,1	547	2,0	2,0
	Máximo		25,7	75,2	7,47	27	0	390	38	38	91	34	28	1,8	634	4,0	2,0
Pablo Noriega	Media	2013-2015	23,1	61,3	7,46	21	0	258	31	0	94	9	8	1,1	421	6012,5	7,3
	Desv-Est		2,9	7,9	0,22	9	0	72	22	0	17	7	4	1,1	62	11991,7	10,5
	Mediana		22,7	57,7	7,47	18	0	287	20	0	100	7	10	0,9	449	24,0	2,0
	Minimo		20,0	56,8	7,18	14	0	153	18	0	70	3	3	0,0	329	2,0	2,0
	Máximo		26,9	73,2	7,71	35	0	305	64	0	108	16	11	2,7	460	24000,0	23,0
Paradero	Media	2013-2015	23,8	60,5	7,20	10	0	331	18	22	100	11	9	1,1	501	117,0	116,5
	Desv-Est		0,6	3,1	0,08	8	0	61	5	22	8	6	4	0,2	85	228,7	229,0
	Mediana		23,9	61,0	7,21	7	0	348	17	14	102	11	10	1,0	520	3,0	2,0
	Minimo		23,0	56,8	7,10	4	0	250	14	8	89	5	3	0,9	384	2,0	2,0
	Máximo		24,5	63,2	7,27	21	0	378	25	54	108	16	11	1,4	579	460,0	460,0
Pedroso	Media	2014-2015	24,1	69,8	7,34	16	0	371	29	24	96	25	20	2,1	576	6,5	2,4
	Desv-Est		2,5	10,0	0,19	7	0	48	8	2	9	11	9	0,7	72	4,2	0,8
	Mediana		25,1	72,3	7,34	20	0	378	32	24	99	28	21	2,3	584	6,6	2,0
	Minimo		20,5	55,7	7,11	5	0	305	18	22	82	9	9	1,1	482	2,0	2,0
	Máximo		25,8	78,9	7,56	20	0	421	35	25	102	35	28	2,7	652	11,0	3,6

Pesca Habana	Media	2013-2015	24,3	87,7	7,35	16	0	376	71	36	92	29	50	2,3	672	2,0	2,0
	Desv-Est		1,9	24,5	0,14	12	0	16	62	17	8	11	36	1,2	127	0,0	0,0
	Mediana		24,9	78,8	7,34	14	0	381	38	33	93	27	37	1,8	624	2,0	2,0
	Minimo		20,8	64,5	7,17	3	0	348	21	18	80	15	17	1,1	542	2,0	2,0
	Máximo		25,8	120,4	7,55	34	0	390	158	59	101	45	94	3,9	835	2,0	2,0
Pozo Redondo	Media	2013-2015	24,2	78,6	7,26	7	0	395	43	39	91	31	30	1,8	630	11,6	2,0
	Desv-Est		1,0	9,5	0,16	8	0	39	29	25	7	8	18	0,9	75	21,5	0,0
	Mediana		24,4	80,3	7,26	5	0	378	35	37	90	34	28	1,8	642	2,0	2,0
	Minimo		22,5	68,7	7,07	1	0	354	20	14	82	18	14	0,8	516	2,0	2,0
	Máximo		25,3	89,1	7,51	21	0	445	94	67	100	37	59	3,3	702	50,0	2,0
Rancho Recreo-1	Media	2013-2015	24,5	68,2	7,04	20	0	360	19	21	124	5	9	4,1	556	4,0	2,0
	Desv-Est		1,0	2,7	0,02	11	0	37	6	5	6	1	3	3,2	23	2,9	0,0
	Mediana		24,1	67,0	7,05	21	0	375	17	23	126	5	10	2,6	566	3,0	2,0
	Minimo		23,8	66,5	7,00	9	0	305	15	14	115	4	4	2,4	521	2,0	2,0
	Máximo		25,9	72,2	7,05	31	0	384	28	23	129	6	10	8,9	570	8,1	2,0
Rancho Recreo-2	Media	2013-2015	24,8	72,8	6,93	30	0	355	25	32	128	5	12	7,1	594	2,0	2,0
	Desv-Est		1,6	4,9	0,22	13	0	54	7	21	13	2	6	3,2	84	0,0	0,0
	Mediana		24,1	73,6	7,02	31	0	381	28	22	132	5	13	8,2	609	2,0	2,0
	Minimo		23,8	66,4	6,60	13	0	275	15	21	110	4	4	2,4	487	2,0	2,0
	Máximo		27,1	77,6	7,09	45	0	384	30	63	138	7	17	9,6	671	2,0	2,0
Raul Garcia	Media	2013-2015	24,0	68,8	7,24	20	0	363	27	35	89	25	19	7,1	576	2,0	2,0
	Desv-Est		1,4	7,3	0,23	4	0	73	6	28	21	8	11	3,2	131	0,0	0,0
	Mediana		23,6	69,4	7,33	21	0	382	25	24	95	29	21	8,2	596	2,0	2,0
	Minimo		22,8	59,3	6,90	15	0	262	21	14	59	13	5	2,4	400	2,0	2,0
	Máximo		26,0	77,0	7,39	24	0	427	35	66	107	30	30	9,6	713	2,0	2,0
San Agustín	Media	2013-2015	22,7	99,0	7,26	14	0	357	168	43	97	28	89	4,5	800	53,3	9,0
	Desv-Est		3,3	22,5	0,24	5	0	36	44	1	8	6	32	0,8	101	88,9	14,0
	Mediana		22,9	106,9	7,35	14	0	369	162	43	95	31	89	4,8	787	2,0	2,0
	Minimo		18,5	67,0	6,90	9	0	305	121	41	90	20	52	3,3	695	2,0	2,0
	Máximo		26,6	115,3	7,43	20	0	384	227	44	107	32	126	5,2	929	156,0	30,0
San Vicente	Media	2009-2015	24,3	74,2	7,30	14	0	376	36	35	91	27	29	2,9	610	7,7	3,8
	Desv-Est		1,3	6,2	0,13	6	0	35	8	16	10	10	8	1,3	48	14,0	2,4
	Mediana		24,8	74,3	7,28	16	0	384	39	31	87	30	32	3,0	622	2,0	3,0
	Minimo		22,3	62,3	7,15	4	0	305	19	11	80	3	11	1,1	495	2,0	2.0
	Máximo		26,1	85,9	7,57	22	0	419	44	73	114	36	37	5,9	668	50,0	7.0
Santa Margarita	Media	2013-2015	23,4	63,9	7,07	22	0	317	26	13	113	4	12	1,1	507	13,0	2,7
	Desv-Est		2,4	9,4	0,32	14	0	61	8	3	22	2	8	0,2	113	12,7	1,2
	Mediana		23,6	61,9	7,19	19	0	336	25	13	114	3	13	1,0	525	12,5	2,0
	Minimo		20,4	55,9	6,60	10	0	232	18	9	85	3	2	0,9	360	2,0	2,0
	Máximo		26,2	75,9	7,30	41	0	366	35	16	138	7	20	1,4	620	25,0	4,0
Santa Mónica	Media	2013-2015	23,4	61,2	7,09	11	0	289	20	0	99	3	9	1,0	433	58,2	2,0
	Desv-Est		1,6	5,8	0,18	5	0	53	5	0	16	2	3	0,4	68	103,1	0,0
	Mediana		23,6	59,5	7,17	9	0	323	18	0	108	4	10	0,9	475	4,0	2,0
	Minimo		20,8	57,7	6,80	8	0	220	15	0	80	1	5	0,7	352	2,0	2,0
	Máximo		25,0	71,5	7,24	19	0	336	25	0	115	5	14	1,8	491	240,0	2,0
Santo Cristo	Media	2009-2015	24,3	58,7	7,37	30	0	283	19	65	103	6	10	4,8	519	592,2	413,5
	Desv-Est		1,4	5,4	0,17	11	0	61	2	149	7	5	5	6,8	167	773,4	684,8
	Mediana		24,2	58,6	7,45	34	0	284	20	18	104	5	8	2,9	489	6,0	6,0
	Minimo		22,5	51,1	7,09	2	0	159	15	14	86	2	3	1,4	345	2,0	2,0
	Máximo		26,1	68,9	7,56	38	0	362	21	488	110	19	17	24,0	955	1600,0	1600,0
Yolando Glez-1	Media	2014-2015	22,5	61,2	7,24	12	0	319	20	190	92	13	10	1,1	658	6,0	2,0
	Desv-Est		0,9	3,8	0,05	4	0	46	2	303	16	5	6	0,4	353	6,9	0,1
	Mediana		22,4	63,1	7,22	13	0	317	20	15	101	13	11	1,1	489	2,0	2,0
	Minimo		21,7	56,8	7,20	8	0	275	18	15	74	9	4	0,7	421	2,0	1,9
	Máximo		23,5	63,7	7,30	15	0	366	21	540	102	18	16	1,4	1064	14,0	2,0
Yolando Glaz-2	Media	2013-2015	23,3	58,5	7,42	14	0	315	21	14	96	11	14	0,9	486	236,1	2,0
	Desv-Est		2,0	4,5	0,25	4	0	27	4	4	9	3	2	0,2	39	601,6	0,0
	Mediana		22,5	58,0	7,41	15	0	311	21	12	92	10	14	0,8	486	2,0	2,0
	Minimo		21,0	53,6	7,19	9	0	281	14	11	88	7	11	0,8	448	2,0	2,0
	Máximo		25,6	67,6	7,86	20	0	368	27	20	108	17	18	1,4	566	1600,0	2,0
Zayas	Media	2009-2015	24,1	71,2	7,34	18	0	362	31	32	91	24	22	1,7	582	3,0	2,0
	Desv-Est		1,3	5,1	0,16	10	0	30	8	15	12	11	10	1,5	49	2,0	0,0
	Mediana		24,1	69,8	7,31	19	0	366	29	29	90	29	22	1,0	572	2,0	2,0
	Minimo		22,4	64,1	7,11	1	0	299	19	11	73	1	2	0,8	497	2,0	2,0
	Máximo		25,8	81,5	7,79	34	0	419	48	71	116	34	37	6,2	683	6,0	2,0
Arroyo Govea (Superf)*	Media	2009-2015	24,0	96,0	7,55	6	0	421	77	33	111	14	59	9,6	730	1,6E+08	2,9E+07
	Desv-Est		1,1	23,3	0,22	4	0	88	42	12	19	8	30	3,9	166	5,6E+08	8,2E+07
	Mediana		24,3	96,0	7,55	9	0	437	66	33	119	12	50	9,6	709	2,0E+04	8,8E+03
	Minimo		21,5	46,1	7,20	1	0	226	25	18	69	5	23	1,0	386	2,3E+01	9,0E+00
	Máximo		25,3	135,1	7,88	10	0	555	156	55	132	38	108	15,2	980	3,0E+08	3,0E+08

*

Estaciones	Estadigrafo	DBO mgL^{-1}	DQO mgL^{-1}
Arroyo Govea (Superf)	Media	52,8	120,9
	Desv-Est	57,3	124,6
	Mediana	27,0	72,5
	Minimo	2,0	14,0
	Máximo	187,0	458,0

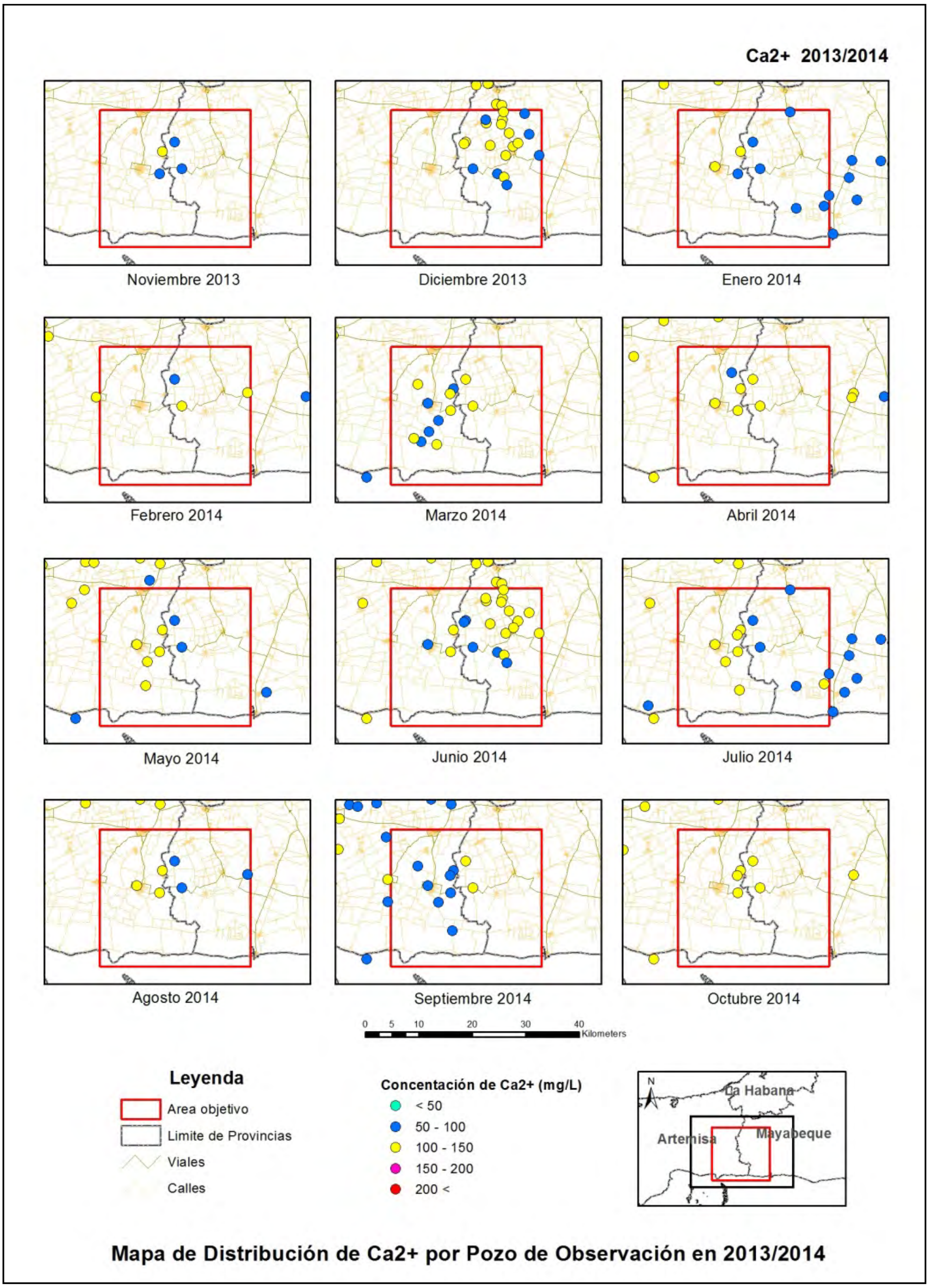

Figure 2-83: Distribution map of Ca2+ in 2013/2014

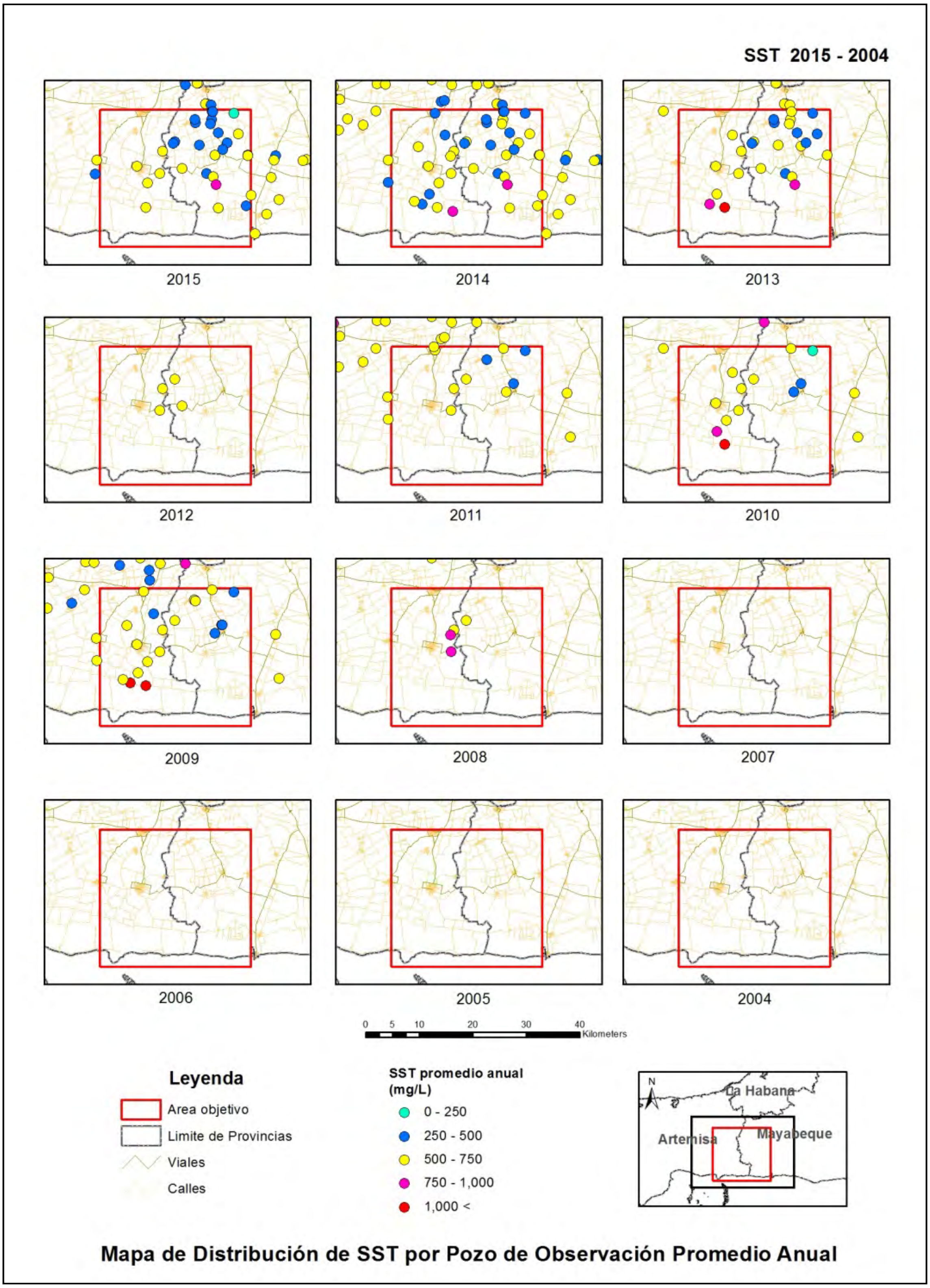

Figure 2-84: TDS annual average distribution map

2.6 Groundwater Balance

The Water Balance, a process leaded and directed by the INRH's system, is the main tool to materialize the integrated water management in Cuba, in order to meet the needs of the economy, the society and the protection of the environment. In the drafting process, major features of mandatory recognition are manifested by the water authority and the respective users. Among them:

1. That it is a renewable natural resource, unlike many other resources that are annually planned and which are inputs of the Economy Plan.
2. That rainfall is the only water renewable source in the country and that it is unevenly distributed in the geographic space and time, with two distinct seasons: rainy and of little rain or dry.
3. That the water authority exercises its own regulatory duty given by the legal instruments at the same time of its drafting, taking into account the points made on the water annual availability in the surface and underground basins.
4. That the water balance, as an expression of the availability-demand relation, goes through both components by means of elements such as uses, rational use, technologies to be used, norms and regulations and others that are also important.

Its execution is governed by the Calendar yearly issued by the National Institute of Water Resources in order to include it in the period of drafting up of the annual plans for the economic and social entities.

The Water Balance, as a planning tool through which efficiency is measured in the state and private intake, regarding the availability of the resource, is a process of conciliating the interests of all branches of the economy and the society in order to access the different water sources to which they are linked.

It is a process of demands, analysis of the availabilities and the technical state of the supplying sources, discussion, justification and allocation of water volumes to meet the set needs, without violating the exploitation conditions and restrictions of the sources. These availabilities depend on the rainfall behavior.

The Artemisa Quivicán HS-3 and the HS-4 underground basins are the main supply sources for the development in this area.

Groundwater formation is mainly due to atmospheric precipitation and by the following complementary supply sources:

- Losses due to filtration of the Pedroso-Güira channel
- River runoff infiltration
- Restitution of irrigation waters

Water infiltration for irrigation is an important factor in the groundwater overall balance. The largest volume of extraction for irrigation, according to historical data was from the year 1987 with 250 x $10^6 m^3$/year. With the existing irrigation methods and the technical condition of the works, the irrigation water restitutions constitute 35% of the exploitation volume taking into account the type of existing rock.

Runoff river infiltration is an element to be considered for the assessment of groundwater resources. In the area of Alturas, where the rocks prior to the Neogene are propagated, the formation of surface runoff occurs. The infiltration to the aquifer is very small in this area, discharging a runoff surface volume in the karstic plain of the Neogene.

Most of the rivers and streams do not reach the coast in the basin. The surface runoff infiltrates into the karstic plain of the Neogene, feeding the groundwater and a part evaporates. Part of the runoff is regulated by the (Aguas Claras) dam and (Vaquería 15, Reyner, Seibabo, San Juan and Añil) micro-dams. Supply is made through losses of leaks from the reservoir.

The direct rainfall infiltration depends on the composition and thickness of the cover sediments in the plain. In the areas where there is an extensive karst development and there are no cover deposits the infiltration can be from 80 to 90% of the precipitation volume.

In these areas, in general, a micro-relief is developed, which has the peculiarity that each surface basin ends in a karstic doline, where a part of the rain runoff arrives. Due to this, the thickness of the cover does not influence the magnitude of the supply.

Losses through the master channels contribute to the aquifer supply. From the water intake of the Derivadora Pedroso dam to Güira de Melena, a channel (Pedroso-Güira) is built of approximately 61 km in length (60,833 km). Total losses vary according to the volumes delivered, and are in the order of 40%.

The groundwater discharge occurs in the form of runoff, through intensely karstified and fractured areas, through the surface flow of the channels located in the swampy area, by the evaporation of the waters embalmed by the south dike and by the exploitation of the wells.

The groundwater extraction is of considerable magnitude, both, by the use of the sources and by the concentration of the exploitation. The main users are aqueducts with a use of 3.2 m^3/s and irrigation systems with a use of 3.5 m^3/s.

The Cuenca Sur aqueduct was built in the 1950s and it consists of 20 exploitation wells, with a depth of between 25 and 90 m, with a total extraction use of 3.02 m^3/s. Agricultural and livestock enterprises of Güira de Melena, 19 de Abril in Quivicán, Alquízar, Batabanó and San Antonio de los Baños are also major groundwater consumers for irrigation.

a. Conceptual diagram of the hydrological cycle

In the case of the study area covered by the JICA Project (including its extension according to the domain of the Mathematical Model), the two variables of the Continuity Equation have been taken into account, with a spatiotemporal approach of the occurrence of the water hydrological cycle in the area, assessing its components at the underground basin level since the so-called JICA Basin constitutes 52 % of the total area of the HS-3 basin and 80 % of it taking the domain area of the Model.

The surface and underground balance will be made integrating both finally with a monthly interval of time, as the formation of the groundwater occurs, mainly, by atmospheric precipitations.

Continuity Equation

$$\Delta V = E - S = dV/dt$$

b. Surface water balance

S According to our area scenario, the Equation is expressed as follows:

$$\Delta V = (Esc) - (Et + In + Inter)$$

Where

ΔV Storage change

V_{ll} Runoff

Et Evapotranspiration

In Rain infiltration towards the deep layers of the ground

Inter Rain blocking by vegetation

c. Component

V_{ll} (Rain runoff): The values of the average rainfall distributed over months were taken

Table 2-15: Average rainfall distributed by months

Concept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	45.9	45.5	47	65.2	138.4	227	172.1	190.4	221.8	131.4	55.6	34.3	1374.6

***In* (Rain infiltration to the deep layers of the ground):** They were determined by the soil water balance taking into account the field capacity, the wilting point, the soil moisture and the apparent density of the soil.

Runoff river infiltration is an element to be considered for the assessment of groundwater resources. In the area of Alturas, where the rocks prior to the Neogene are propagated, the formation of surface runoff occurs. The infiltration to the aquifer is very small in this area, discharging a runoff surface volume in the karstic plain of the Neogene.

The direct infiltration of precipitations depends on the composition and thickness of the cover sediments in the plain. In the areas where there is an extensive karst development and there are no cover deposits the infiltration can be from 80 to 90 % of the precipitation volume.

In these areas, in general, a micro-relief is developed, which has the peculiarity that each surface basin ends in a karstic doline, where a part of the rain runoff arrives. Due to this, the thickness of the cover does not influence the magnitude of the supply.

***Inter* (Rain blocking by vegetation):** The values determined by the previous Balance using the coefficients of the methodology were taken.

d. Methodology

In the case of the components for Runoff, Infiltration, Actual Evapotranspiration and Natural Recharge, they were determined by the Schosinsky Methodology, 2006 which uses the Water Balance of soils supported by the zonification of Biophysical Polygons (Rodríguez, Álvarez, 2014). The procedure is the following:

- Determining the value of actual evapotranspiration.
- Determining the value of the relationship between water infiltration in the soil and rainfall intensity (Kfc factor).

- Determining the slope value (Kp factor).
- Determining the value of the vegetation cover (Kv factor).
- Determining the retention value of covers (roofs, etc.).
- Calculating the value of the infiltration coefficient Ci=Kfc+Kp+Kv.
- Determining the value of the effective precipitation Pef.
- Calculating the soil water balance.

According to the slope, soil texture, and vegetation cover, 3 polygons where zonified where the climatic variables of rainfall, temperature and solar radiation were applied and other parameters such as field capacity, wilting point, soil moisture and its apparent density, obtaining the Soil Water Balance.

fc [mm/d]	600,00			
Kp [0.01%]	0,15			
Kv [0.01%]	0,20		por peso	
Kfc [0.01%]	0,89258		(%)	(mm)
I [0.01%]	1	CC	37,00	325,60
DS (g/cm^3):	1,10	PM	30,00	264,00
PR (mm)	800,00	(CC-PM)	7,00	61,60
HSi (mm)	325,60			
Nº de mes con que inicia HSi;1,2,3...12?	11			
Lluvia retenida [0.01%] : Bosques=0.2, otros=0.12	0,12			

Concepto	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	Total
P (mm)	45.90	45.50	47.00	65.20	138.40	227.00	172.10	190.40	221.80	131.40	55.60	34.30	1374.60
Ret [mm]	5.51	5.46	5.64	7.82	16.61	27.24	20.65	22.85	26.62	15.77	6.67	5.00	165.84
Pi (mm)	40.39	40.04	41.36	57.38	121.79	199.76	151.45	167.55	195.18	115.63	48.93	29.30	1208.76
ESC (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ETP (mm)	54.90	42.40	50.10	65.20	70.50	93.60	140.40	149.10	95.80	99.50	90.10	40.80	992.40
HSi (mm)	310.51	309.19	313.29	313.11	316.04	325.60	325.60	325.60	325.60	325.60	325.60	314.54	
C1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
C2	0.52	0.70	0.66	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.33	0.63	
HD (mm)	86.90	85.23	90.65	106.49	173.83	261.36	213.05	229.15	256.78	177.23	110.53	79.84	
ETR (mm)	41.71	35.94	41.54	54.45	70.50	93.60	140.40	149.10	95.80	99.50	59.99	33.33	915.86
HSf (mm)	309.19	313.29	313.11	316.04	325.60	325.60	325.60	325.60	325.60	325.60	314.54	310.51	
DCC (mm)	16.41	12.31	12.49	9.56	0.00	0.00	0.00	0.00	0.00	0.00	11.06	15.09	
Rp (mm)	0.00	0.00	0.00	0.00	41.73	106.16	11.05	18.45	99.38	16.13	0.00	0.00	292.90
NR (mm)	29.60	18.77	21.05	20.31	0.00	0.00	0.00	0.00	0.00	0.00	41.17	22.56	153.46

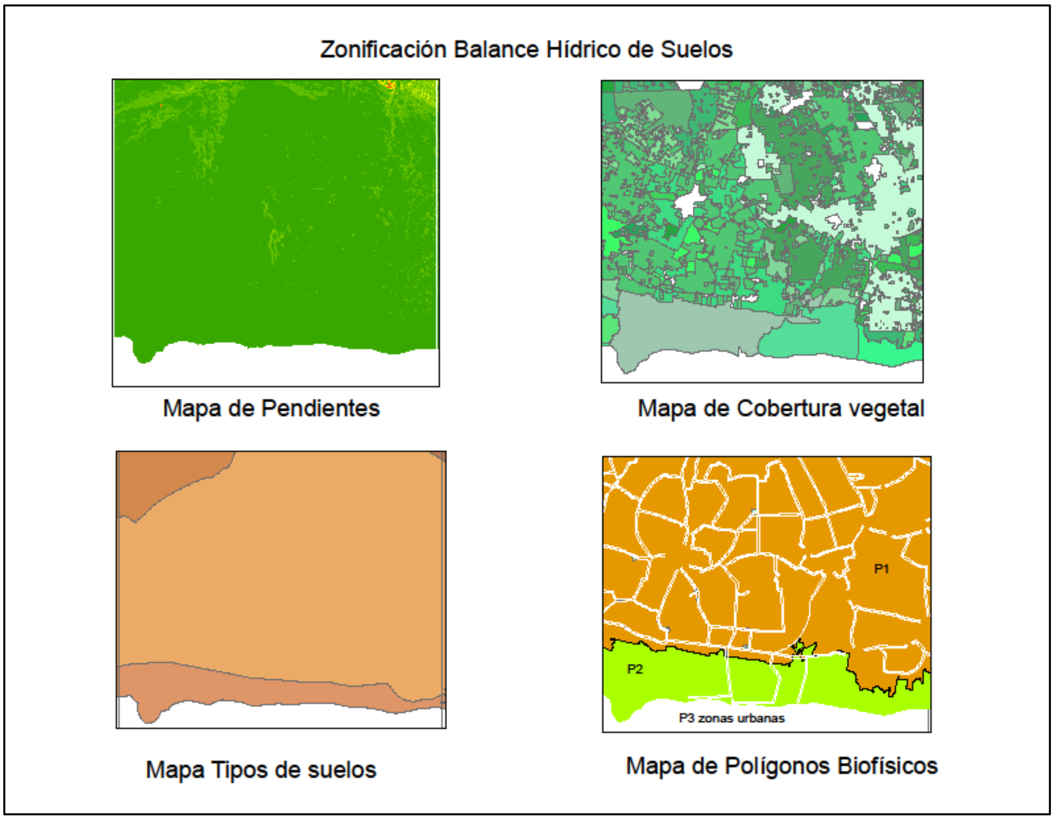

Figure 2-85: Zonification for the soil water balance

Table 2-16: Coefficients per slope

Coefficient for slope, Guara Basin		
Classification	Slope	Kp
Very flat	0.002	0.30
Flat	0.004	0.20
A bit flat	0.014	0.15

Table 2-17: Coefficient per vegetation cover

No.	Vegetation cover	Kv
1	Assorted crops	0,10
2	Pasture	0,18
3	Secondary forests, bushes	0,20
4	Mangroves	0.20
5	Swamp meadow	0.20

Table 2-18: Coefficients in other areas

Other areas	Coeff. Kfc	Coeff. Kv	Average annual rain	Coeff. Kp
Reservoirs	0.10	0	according to the area	according to the area
Urban areas	0.10	0.18	according to the area	0,20
Roads	0.10	0.18	according to the area	0.20

Table 2-19: Root depths

Crop	Root depths (m). Modification of Schosinsky
Pasture	Between 1.40 and 1.60
Swamp meadow	1.00
Assorted crops	Between 0.70 and 0.50
Mangroves	1.70
Forests	2.00

Table 2-20: Coefficients per types of soils

No	Genetic classification	Percentage by the weight of the dry soil			
		PM (cm^3/cm^3)	CC (cm^3/cm^3)	DA (g/cm^3)	fc (mm/day)
1	Sialitic Brown	34	42	1.31	700
2	Fersialitic	28	34	1.04	800
3	Fluvisol	30	37	1.11	1400
4	Ferralitic	30	37	1.11	1900
5	Hydromorphic	35	44	1.06	1800
6	Humic	30	40	1.19	600
7	Hydromorphic - histosol	35	44	1.06	1800
8	Ferralitic	30	37	1.11	600

Table 2-21: Soil Water Balance (2015)

Variables	J	F	M	A	M	J	J	A	S	O	N	D	Annual
P (m3)	316710	313950	324300	449880	954960	1566300	1187490	1313760	1530420	906660	383640	236670	9484740
Ret (m3)	41657	41282	42643	59132	125582	205956	156134	172761	201262	119231	50434	36344	1252417
Pi (m3)	265683	263376	272062	377433	801121	1313996	996217	1102122	1283870	760600	321851	193526	7951863
ESC (m3)	9370	9292	9595	13311	28261	46348	35139	38877	45288	26829	11351	6800	280460
ETR (m3)	277487	236646	274435	360305	473867	629134	941717	1002083	643922	668791	411095	219638	6139122
Rp (m3)	0	0	0	0	242078	676609	61337	104922	632685	95133	0	0	1812737

Table 2-22: Components of the Water Balance

Rainfall	Infiltration	Runoff	Evapotranspiration	Foliage retention	Recharge
m^3/year					
9.484	7.952	0.280	6.139	1.252	1.812

These values are used to draw up the diagram of the hydrological cycle.

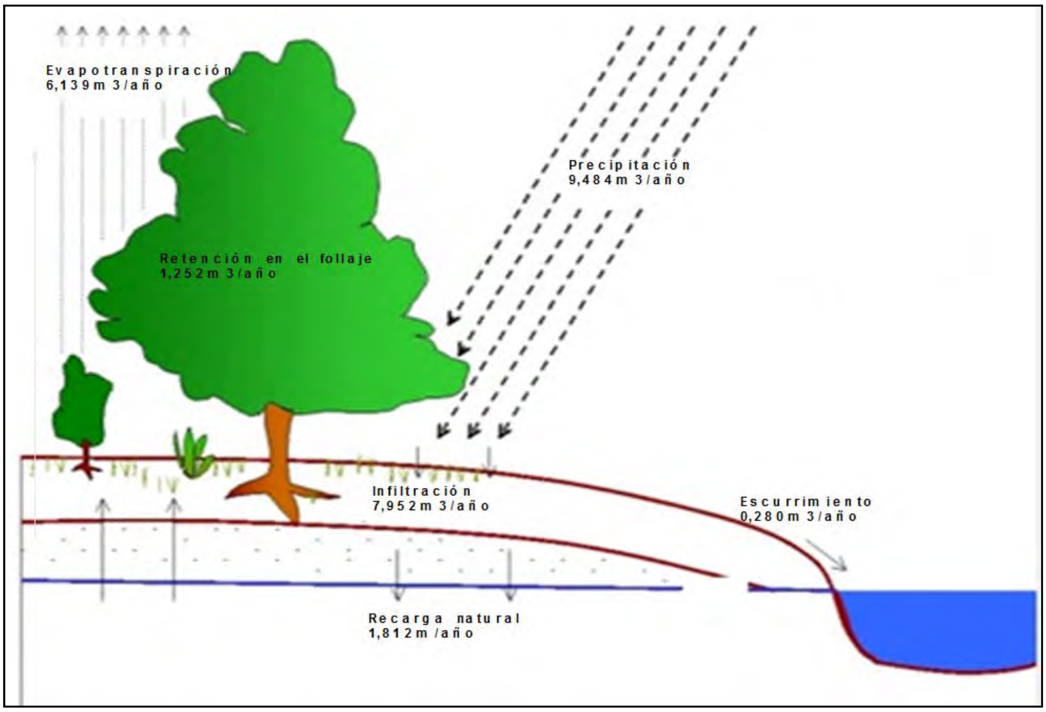

Figure 2-86: Hydrological cycle diagram

As it can be seen, 66% of the precipitations fallen infiltrates, of which the 16% to become natural recharge and 82% is used by plants. This is evidenced because different crops abound in the area and a mangrove ecosystem spreads on the coast. The remaining 19% runs mainly in roads and urban areas and 15% of the rainfall is intercepted by foliage.

Resource Assessment

The following expression was used to calculate the available resource, which depends on the hydrological season, the dry season (November-April) and the wet season (May-October):

$$Rdis = \Delta H \ \mu . \ F$$

Where:

μ.- Is the storage coefficient (dimensionless)

ΔH.- Is the effective recharge of the aquifer in m

F.- Is the sub-basin area in km^2

The effective recharge is calculated by the Groundwater Balance Control Graph, for which rainfall data (mm), water levels (m) and groundwater exploitation by aqueducts data are entered monthly to a software developed for this purpose (Pons, 1980). This program also allows to solve the net recharge and the supply coefficient, among other variables.

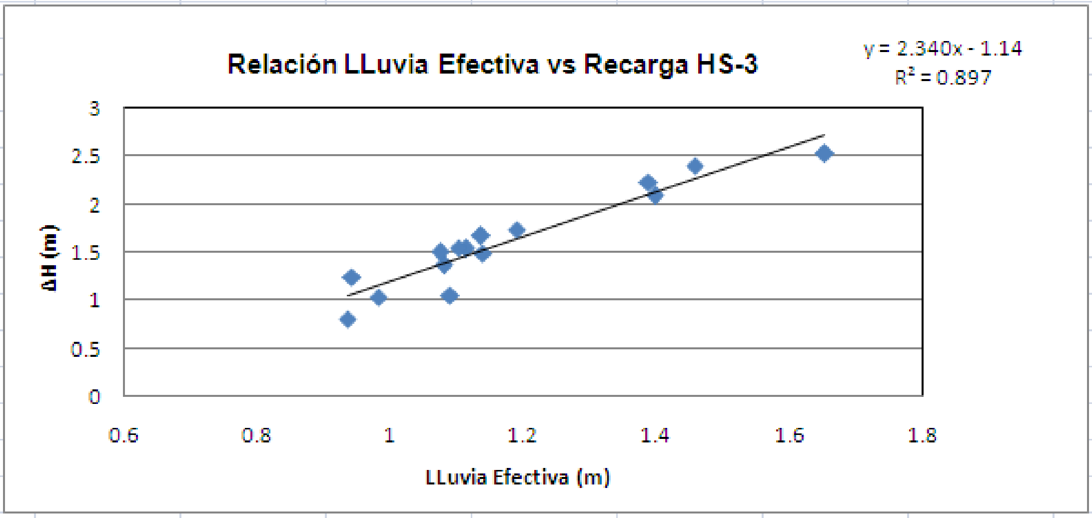

Figure 2-87: Estimation of the total effective recharge starting from the effective rainfall

$$\Delta H = 2.340 * LLe - 1.14$$

R^2=0.897 (Correlation Coefficient)

Where:
ΔH Effective Total Recharge (m)

Effective Rain (m). Rainfall accumulated in the wet season. (May-October).

- Recharge probabilities relative to the effective rainfall.

A statistical analysis was performed on the effective rainfall series of 1986-2014 applying goodness-of-fit tests to theoretical probability distributions by the Smirnov-Kolmogorov method. The result will be used to evaluate available resources with different probabilities.

Procedure to Evaluate Available Resources at the end of the Wet Season

- From the effective rainfall obtained at different probabilities with the aid of the of ΔH vs Lle graph and with its regression equation, the value of ΔH is determined for that probability.
- The recharged volume (Vr) for the mean probability is calculated by the Binderman balance equation (1) with the mean ΔH, from the ΔH previously calculated by regression to the different probabilities, and are replaced according to the 2, 3 and 4 equations:

$$Vr = \mu.\overline{\Delta H} F \quad (1)$$

$$Vr = \mu.\Delta H_{25\%} F \quad (2)$$

$$Vr = \mu.\Delta H_{75\%} F \quad (3)$$

$Vr = \mu.\Delta H_{95\%} F$ (4)

- The supply value of the aquifer horizon at different probabilities is determined using the calculated value of ΔH at different probabilities by the equation (7), which gives us the mean W for the mean ΔH

$W = \mu.\Delta H_{25\%}$ (5)

$W = \mu.\Delta H_{75\%}$ (6)

$W = \mu.\Delta H_{95\%}$ (7)

$W = \mu.\overline{\Delta H}$ media (8)

- Values of the supply coefficient (α) at different probabilities are obtained by the following relations:

$\alpha = \frac{W_{25\%}}{Lle_{25\%}}$ to 25% of probability

$\alpha = \frac{W_{75\%}}{Lle_{75\%}}$ to 75% of probability

$\alpha = \frac{W_{95\%}}{Lle_{95\%}}$ to 95% of probability

$\alpha = \frac{\overline{W}}{\overline{Lle}}$ for the mean probability

Table 2-23: Available resource to different probabilities

Probabilities	LLe (mm)	ΔH (m)	W (m)	Vr Available Resource (H^3/Year)	α (%)
25%	1259.1	1.81	0.307	297.24	0.244
75%	1013.9	1.23	0.210	202.82	0.207
95%	867.4	0.89	0.151	146.41	0.174
Mean	1046.8	1.31	0.22	215.493	0.208

The procedure described is performed at the end of each wet season, evaluating the available resource, which will be the recommended exploitation volume for the next hydrological year.

Table 2-24: Internal balance of the aquifer obtained by the methodology of the balance control graph (GCBAS)

N	Año	Δh(m)	Δzh(m)	Δzs(m)	ΔH(m)	ΔZ(m)	Lle(mm)	α	W(m)	u	Mo	Vr (hm3)	Vexp(hm3)
1	1986	1.18	1.64	1.11	2.82	2.75	962	0.499	0.48	0.17	15.22	464.64	453.11
2	1987	0.87	0.17	1	1.04	1.17	981	0.1835	0.18	0.17	5.71	174.24	196.02
3	1988	1.23	0.14	1.11	1.37	1.25	1080	0.2222	0.24	0.18	7.61	232.32	211.97
4	1989	1.25	-0.19	1.24	1.06	1.05	1090	0.1651	0.18	0.17	5.71	174.24	172.60
5	1990	1.07	-0.11	0.99	0.96	0.88	1103	0.1451	0.16	0.17	5.07	154.88	141.97
6	1991	1.47	0.62	1.16	2.09	1.78	1397	0.2577	0.36	0.17	11.41	348.48	296.79
7	1992	2.05	0.72	1.1	2.77	1.82	1318	0.3642	0.48	0.17	15.22	464.64	305.29
8	1993	0.68	0.1	1	0.78	1.1	1163	0.1118	0.13	0.17	4.12	125.84	177.47
9	1994	1.01	-0.2	1.58	0.81	1.38	935	0.1497	0.14	0.17	4.44	135.52	230.89
10	1995	1.04	0.7	0.71	1.74	1.41	1189	0.2523	0.3	0.17	9.51	290.4	235.32
11	1996	1.11	0.43	1.17	1.54	1.6	1113	0.2336	0.26	0.17	8.24	251.68	261.49
12	1997	0.84	0.71	0.71	1.55	1.42	1102	0.245	0.27	0.17	8.56	261.36	239.44
13	1998	0.99	0.5	1.32	1.49	1.82	1139	0.2283	0.26	0.17	8.24	251.68	307.42
14	1999	2.05	1.19	1.67	3.24	2.86	1174	0.4685	0.55	0.17	17.44	532.4	469.96
15	2000	0.73	2.02	0.92	2.75	2.94	923	0.5092	0.47	0.17	14.90	454.96	486.39
16	2001	1.09	1.03	0.92	2.12	1.95	1087	0.3312	0.36	0.17	11.41	348.48	320.54
17	2002	1.59	0.64	0.69	2.23	1.33	1388	0.2738	0.38	0.17	12.05	367.84	219.38
18	2003	0.63	0.62	1.09	1.25	1.71	942	0.2229	0.21	0.17	6.66	203.28	278.09
19	2004	0.6	0.87	0.83	1.47	1.7	1117	0.2238	0.25	0.17	7.93	242	279.86
20	2005	1.84	0.69	1.39	2.53	2.08	1653	0.2601	0.43	0.17	13.63	416.24	342.21
21	2006	0.82	0.85	1.1	1.67	1.95	1136	0.2553	0.29	0.17	9.19	280.72	327.79
22	2007	0.68	0.79	0.87	1.47	1.66	1237	0.2021	0.25	0.17	7.93	242	273.28
23	2008	1.35	1.06	1.42	2.41	2.48	1458	0.2812	0.41	0.17	13.00	396.88	408.41
24	2009	0.27	1.28	0.51	1.55	1.79	916	0.2948	0.27	0.17	8.56	261.36	301.83
25	2010	0.44	0.3	0.63	0.74	0.93	1058	0.1229	0.13	0.18	4.12	125.84	158.15
26	2011	1.05	0.45	1.05	1.5	1.5	1074	0.2421	0.26	0.17	8.24	251.68	251.68
27	2012	1.51	1.29	1.51	2.8	2.8	1487	0.3228	0.48	0.17	15.22	464.64	464.64
28	2013	1.07	0.82	1.07	1.89	1.89	1141	0.2805	0.32	0.17	10.14	309.76	309.76
29	2014	0.29	1.18	0.29	1.47	1.47	823	0.3038	0.25	0.17	7.93	242	242.00

- Δh: Net Recharge (m) (Level Rises) The following procedure has been followed for this calculation: within the year the lowest value of the (peak) level is identified and subtracted from the preceding one (depression) if there is only one peak. If there are 2 peaks, the calculation is made in the same way and they are added up. When the elevation of the level (peak) transcends in an ascending manner from one year to the next this value is added to that of the previous year.
- ΔZh**:** Discharge in the wet season (m) It is determined by calculating the downward trend in the dry season and multiplying it by the months that pass until the net recharge corresponding to that ΔZh, that is to say = $\frac{\Delta Zs}{t_{\sec o}} * t_{humedo}$. It can also be calculated by applying the properties of inner triangles.
- ΔZs, Net Discharge (m) (Level decreases) The following procedure has been followed for this calculation: the highest value of the (depression) level is identified within the year and the previous one is subtracted from it, provided that the trend is towards a decrease if there is only one depression. If there are 2 depressions, both are calculated in the same way and added up. This value shall be always included in the year that corresponds to the preceding Δh.

- ΔH: Total Apparent Height of the Supply (m). It is obtained from the sum of Δh and ΔZh, locating it in the corresponding year. ΔH= Δh +ΔZh

1.

- ΔZ: Total Apparent Height of the Supply (m). It is obtained from the sum of Δh and ΔZh, locating it in the corresponding year. ΔZ= ΔZs +ΔZh.
- Lle: Effective Rainfall (mm). It is the sum of all monthly rainfall that causes a variation in the trend of to the fall of the levels within the year.
- µ: Effective Porosity or Storage Coefficient (Adim) It can be calculated by the following equation: u= 0.17.
- W: Aquifer Supply (m); Is the product of µ and ΔH; that is to say W= $\mu * \Delta H$
- α : Mean annual runoff coefficient is the magnitude obtained from the division of the aquifer supply (W) and the effective rain LLe; that is to say $\alpha = \frac{W}{Lle}$

2.

- Vr: Recharge Volume (hm^3). It is obtained by: Vr= $\mu * \Delta H * F$
- Vexp: Volume of Exploitation (hm3) is obtained by: Vexp= $\mu * \Delta Z * F$

3.

Where F is the area of the Basin F= 968Km2

<u>Obtaining the Warning Levels</u>

- Nalert: Alert level (m), $Nalerta = NM\,\mathrm{Re}g - \overline{\Delta h}$
- Aalarm: Alarm level (m), $Nalarma = NM\,\mathrm{Re}\,g - \frac{\overline{\Delta h}}{2}$

e. Groundwater balance

Adapting the continuity equation to the hydrogeological scenario in the area

$$\Delta V = (In + R_t + V_{man} + f + \Delta h) - (Uc + A_b + E_x)$$

Where

ΔV	Storage change
Rt	Water returns from various uses (35% depending on the type of rock)
V_{man}	Contributions from other basins
In	Rain infiltration towards the deep layers of the ground
Uc	Water uses (consumption or not), equivalent to the demand
f	Leakage losses in municipal systems. (20% according to NC 973/2013)
A_b	Runoff volume to the exit of the basin (Q = L i T)
Ex	Exports to neighboring basins

f. Components

***Rt* (Water returns from the different uses):** The irrigation systems and the master channels contributions were determined.

Irrigation waters restitution

Water infiltration for irrigation is an important factor in the groundwater overall balance. In the last 5 years, these values have decreased considerably as the volumes delivered to the users do not exceed 80 Hm³/year. In addition, agriculture has gained veracity in the water volumes demanded, irrigation techniques have been introduced with higher efficiency, such as the hose reel irrigation system whose efficiency is of 85% which makes that irrigation water restitutions be between 15 and 20% of the exploitation volume in the humid season. Nevertheless, 35% of the volume consumed according to the type of rock in the area was applied.

Losses due to filtration of the Pedroso-Güira channel

Losses through the master channels contribute to the aquifer supply. From the work of the water intake of the Derivadora Pedroso, up to Güira de Melena, a channel (Pedroso-Güira) is built of approximately 61 km in length where the losses by conduction constitute a recharge of the aquifer. The master channels in the study area reach 26.575 km, of which 23.885 km belong to the Pedroso-Güira channel (specifically, Section III), which crosses the entire study area from the San Felipe river to the Güira I Regulatory Reservoir in the village of El Gabriel already in the province of Artemisa and 2.69 km to the Aguas Claras channel that gives continuity to a siphon coming from the Aguas Claras dam until the Buenaventura Regulatory Reservoir in the town of the same name.

Both hydraulic works are lined with concrete slabs, and provide volumes that constitute groundwater recharge during the 9 months of operation. Due to the large extension of the Pedroso Güira channel (from the Pedroso Derivation Plant to Güira de Melena 60.883 Km), it was divided into 3 sections to study of the losses by conduction and precisely the project area coincides with Section III, which due to the inadequate conditions of the union joints between the slabs, it has a 60% efficiency. In the case of the Aguas Claras channel, the coating that has the filter under the slabs with polyethylene has greater efficiency although it has decreased in the last years to 85% due to water conflicts. Despite having a smaller length, this channel is located in the recharge area of the aquifer.

From the hydrophysical properties of the Cuban soils (Hernández, et al, 1999) and the Soil Grouping Map (ENPA, 2010), it can be observed that the predominant type of soil is the typical red ferralitic and humic red ferralitic, whose basic infiltration coefficients are in the order of 1900mm/day and 600mm/day (Cid et al, 2011).

IMTA, 2006 states that an additional method to determine agricultural returns is to consider the difference between the actual volumes supplied from the source and what was consumed by the client, estimating the percentages of infiltrated water according to the type of soil and the effective porosity of rocks. In our case, the effective recharge of the Groundwater Balance Control Graph (GCBAS by its Spanish initials) 26% of the rainfall is taken.

Figure 2-88: Recharge for channel losses

V_{man} (Contributions from other basins): The area reaches annually surface water volumes from the neighboring Mayabeque basin and groundwater volumes from the Ariguanabo basin. Also, in the third quarter of the year, the ecologic use of the Quivicán River also contributes through the Aguas Claras reservoir.

***In (*Rain infiltration towards the deep layers of the ground):** The values taken were those of the natural recharge determined by the previous Balance.

River runoff infiltration

Most of the rivers and streams do not reach the coast in the basin. The surface runoff infiltrates into the karstic plain of the Neogene, supplying the groundwater and a part of it evaporates. Part of the runoff is regulated by the (Aguas Claras) dam and (Vaquería 15, Reyner, Seibabo, San Juan and Añil) micro-dams in the pre-high area. Supply is made through leakage losses from the reservoir.

Infiltration coefficients, determined in previous investigations, vary in a wide range, from 30% to 70%, which is in accordance with the result obtained.

The groundwater discharge occurs in the form of runoff, through intensely karstified and fractured areas, through the surface flow of the channels located in the swampy area, by the evaporation of the waters embalmed by the south dike and by the exploitation of the wells.

***Uc* Water uses (consumption or not), equivalent to the demand:** The extraction values taken are those of the 2015 users.

The groundwater extraction is of considerable magnitude, both, by the use of the sources and by the concentration of the exploitation. The Cuenca Sur aqueduct was built in the 1950s and it consists of 20 exploitation wells, with a depth of between 25 and 90 m, with a total extraction use of 3.02 m^3/s. From 1976 on, information was gathered in this aqueduct of the periodic controls of mineralization, exploitation and dynamic levels, where it can be observed that more than half of the wells are pumping below the mean sea level (2 to 6 m) and only 4 have a rise in Chlorides from 50 to 100 mg/l from 1985. The rest of the wells pump with dynamic levels above the mean sea level and half of them show a rise in Chlorides from 1985.

***f (*Leakage losses in municipal systems):** The NC 973/2013 standard sets out that in those systems with deteriorated sanitary installations, an estimate of 20% of losses is taken.

Δh (Sounded Net Recharge Volume): The recharge values obtained by the Groundwater Balance Control Graph are entered, as the artificial recharge volumes are collected in this component.

Ex **(Exports to neighboring basins):** As it is the largest consumer, the intake data of the Cuenca Sur Aqueduct was taken and exported to the Vento basin.

A_b (Runoff volume to the exit of the basin): It is proposed to implement a hydrometric control system in the spillways of the Dique Sur that constitutes a control section to know the volume and discharge of the aquifer.

g. Integrated water (surface water and groundwater) balance

Once selected, all variables are unified for the execution of the balance in the study area with a monthly distribution. These differences in volume will allow us to know if there is a deficit in the intake demanded by the clients for different uses.

The entire potential resource of the HS-3 basin was also taken into account for the analysis and the exploitation of all the clients of both provinces, Artemisa and Mayabeque.

With these figures, the HIDROGES software is run and the results of the water availability are informed to the users.

The Balance Book is included as an appendix containing the following:

- Table 1: Summary by organizations
- Table 2: Summary by types of water
- Table 4: Summary by source and types of water
- Table 6: Summary by organizations and types of water
- Table 7: Summary by crops
- DH2: Control of the Water Balance

Table 2-25: Water balance JICA (2015) basin

MONTHS	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
ΔV Storage change	-13121577	-13095508	-13126330	-13220486	8468619	54279705	7389623	20990644	8075929	3540275	-110056	-13068213	37002625
V_{ll} Initial volumen of the HS-3 aquifer	316444000	303322423	290226915	277100584	263880098	272348717	326628422	334018046	355008690	363084619	366624894	366514838	**353446625**
Runoff	9372	9290	9597	13313	28259	46349	35140	38876	45288	26830	11353	6798	**280464**
Im Imports from neighboring basins	2451468	2451468	2451468	2451468	2461663	2461663	2797330	2797330	2797330	2452591	2452591	2452591	**30478961**
- Cuenca Ariguanabo basin river flow	5357	5357	5357	5357	15552	15552	15552	15552	15552	6480	6480	6480	**118628**
- Mayabeque basin	2446111	2446111	2446111	2446111	2446111	2446111	2446111	2446111	2446111	2446111	2446111	2446111	**29353332**
- Quivicán basin	0	0	0	0	0	0	335667	335667	335667	0	0	0	**1007001**
Rt Irrigation and channel water returns	13167088	13167088	13167088	13167088	13167088	13167088	12980310	12980310	12980310	13167088	13167088	13167088	**157444722**
- Returns through master channels	186778	186778	186778	186778	186778	186778	0	0	0	186778	186778	186778	**1681002**
- Water returns from irrigation systems	12980310	12980310	12980310	12980310	12980310	12980310	12980310	12980310	12980310	12980310	12980310	12980310	**155763720**
In (Natural infiltration)	47193	39561	43160	44753	231671	589382	64033	102442	551763	89562	45219	37108	**1885848**
Δh Net recharge according to GCBAS	0	0	0	0	21669000	66820000	11294000	12779000	0	17050000	13130000	0	**142742000**
f Leakage losses (20% Use)	800000	800000	800000	800000	800000	800000	800000	800000	800000	800000	800000	800000	**9600000**
Uc Uses MAY and ART	21048000	21048000	21048000	21048000	21048000	21048000	0	0	0	21048000	21048000	21048000	**189432000**
Ex Exports to neighboring basins (Ac Cuenca Sur)	8250000	8250000	8250000	8250000	8250000	8250000	8250000	8250000	8250000	8250000	8250000	8250000	**99000000**
Et Evapotranspiration	236667	203425	236125	310993	404022	536404	804606	854368	549012	570216	343166	187128	**5236132**
Inter Rain blocking by vegetation	62031	61491	63518	88114	187040	306778	232583	257315	299750	177580	75140	46670	**1858009**
A_b Downstream runoff	0	0	0	0	0	0	0	0	0	0	0	0	**0**
V_{ll} Final volume of the HS-3 aquifer	303322423	290226915	277100584	263880098	272348717	326628422	334018046	355008690	363084619	366624894	366514838	353446625	
Condition	Downward	Downward	Downward	Downward	Upward	Upward	Upward	Upward	Upward	Upward	Downward	Downward	Upward

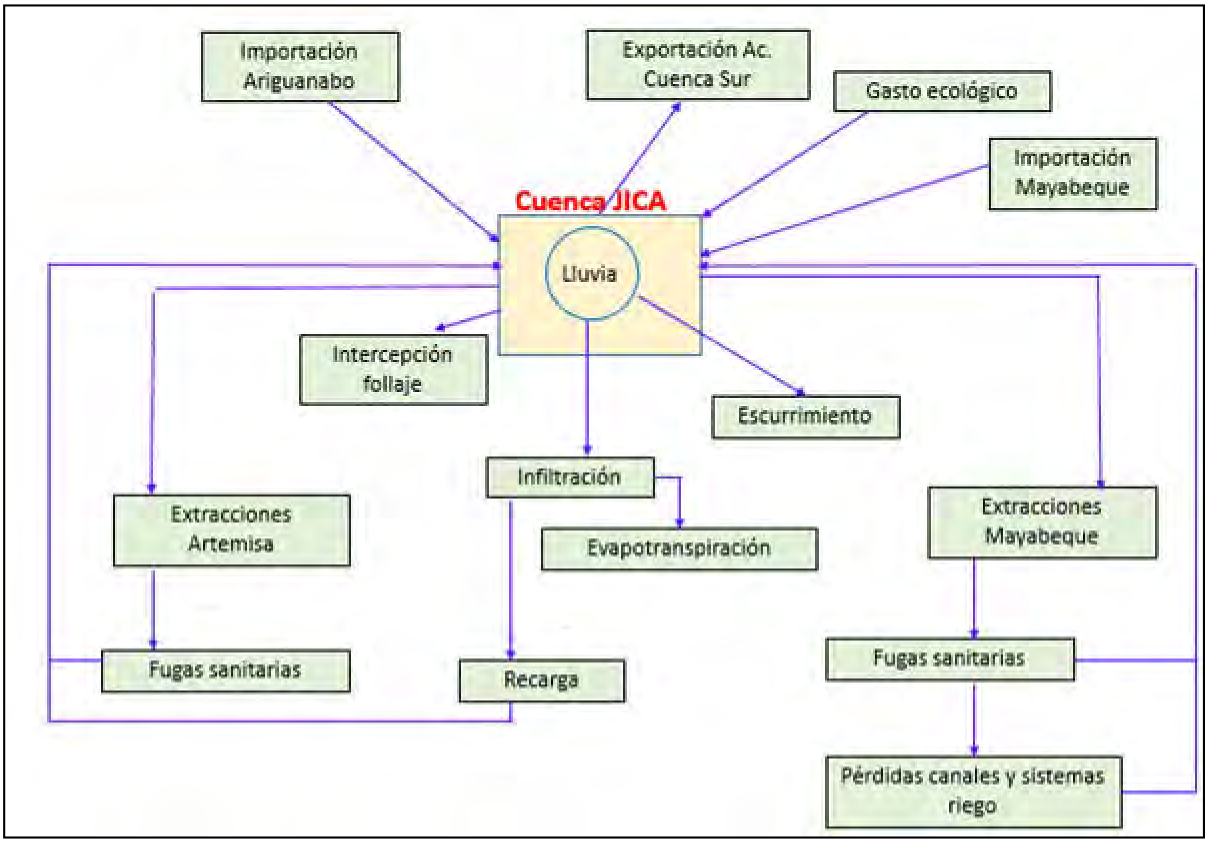

Figure 2-89: Diagram of surface and underground water balance

2.7 Groundwater Problems

a. Groundwater levels

It is not possible to perform the quality groundwater analysis without making an incursion into the water level of the aquifers involved in the study. This is why we have decided to go deeper into this subject.

When a basin is exploited, it is susceptible to be affected mainly by two secondary negative effects, such as those related to level downwards and those related to changes in the hydrochemical composition and/or water quality. These will have the following characteristics:

- Progressive downward of underground levels, which in turn causes secondary pumping problems (air pumping, need to increase the depth of wells, greater drawdown, cost aggravations, etc.).
- Partial loss of stored water reserves.
- Alteration of the quality and/or groundwater hydrochemical composition by the dragging of polluting substances.
- Progressive increase of salinity (due to seawater intrusion) in open basins, when the pumping exceeds the basin’s possibilities of use.

From the point of view of the use, the following situations have taken place in the study area:

- Decrease in the storage volumes of renewable and permanent reserves in the basin.
- Significant decrease in the average historical levels of the aquifer.
- Excess of salinity in the soil.
- Excess salinity for crops.
- Direct use of sources contaminated by high mineralization.
- Action on the health of humans and animals.
- Increase of the seawater intrusion due to an excessive extraction of the resources available.
- Organic dragging by direct and indirect spills in the aquifer.
- Appearance of large pumping cones due to high concentration of the extractions.
- Negative effects caused from irrigation and drainage when they have not been properly designed and/or operated.

It has been checked that he 1.0 m elevation water table outline is approximately 15 km further away from the coast in the central area than at the ends.

b. Groundwater quality

The salinity values in the waters of the pumping wells have significantly increased due to the critical situation in the Artemisa-Quivicán basin of the Southern Coast of Havana, where the seawater intrusion penetrated for years caused by the intense agricultural exploitation and the supply to the capital (Cuenca Sur Aqueduct), the low percentage or rainfall deficit and also to the destabilizing effect of the underground regime, caused by the channels that drained the aquifer. This has jeopardized the guaranteed delivery of the volumes committed, and what is worse, the irreversible deterioration of the quality of the underground water resources of this basin.

For more than 50 years, drainage channels have been built in the coastal zones, which were carried out without hydrogeological studies and with several objectives: wood and coal extraction, for soil improvement and recovery of some areas, for maritime coastal works and as fast transit routes for the personnel working in such remote areas.

By draining the aquifer in this way, its natural conditions were altered (the hydraulic load decreased and the free drainage to the sea was increased), which favored or accelerated the mixing of freshwater and saltwater with the consequent seawater penetration.

The inadequate construction of the wells of the Cuenca Sur aqueduct and the pump installation, which, together with the extraction and specific hydrogeological characteristics of the territory, have influenced the upper part of the diffusion zone, creating salinity problems that can be considered as local and not regional.

b.1 Seawater intrusion

In this Llanura Sur Havana-Matanzas where the Mayabeque and Artemisa provinces are mainly involved, the province of Havana is also of influence with some of its bordering municipalities.

Practically from the creation of the Republic after the colonization by Spain, there was a development in the reference area of the productive increase of the lands with all the necessary elements for the cultures known as minors, which are so necessary for the human consumption.

This allowed that some large and small producers develop drainages in the area in order to obtain fertile lands for the seasonal crops without considering that these channels would allow the increase of the salinity in the groundwater that were used for irrigation. With the triumph of the Revolution, the productive levels increased, and, as a result, the water intake of the different aquifers increased, until finally non-expected salinity levels are observed which cause a development of studies necessary to know the water table condition and a set of measures are taken that allow to attenuate the increase of the salinity.

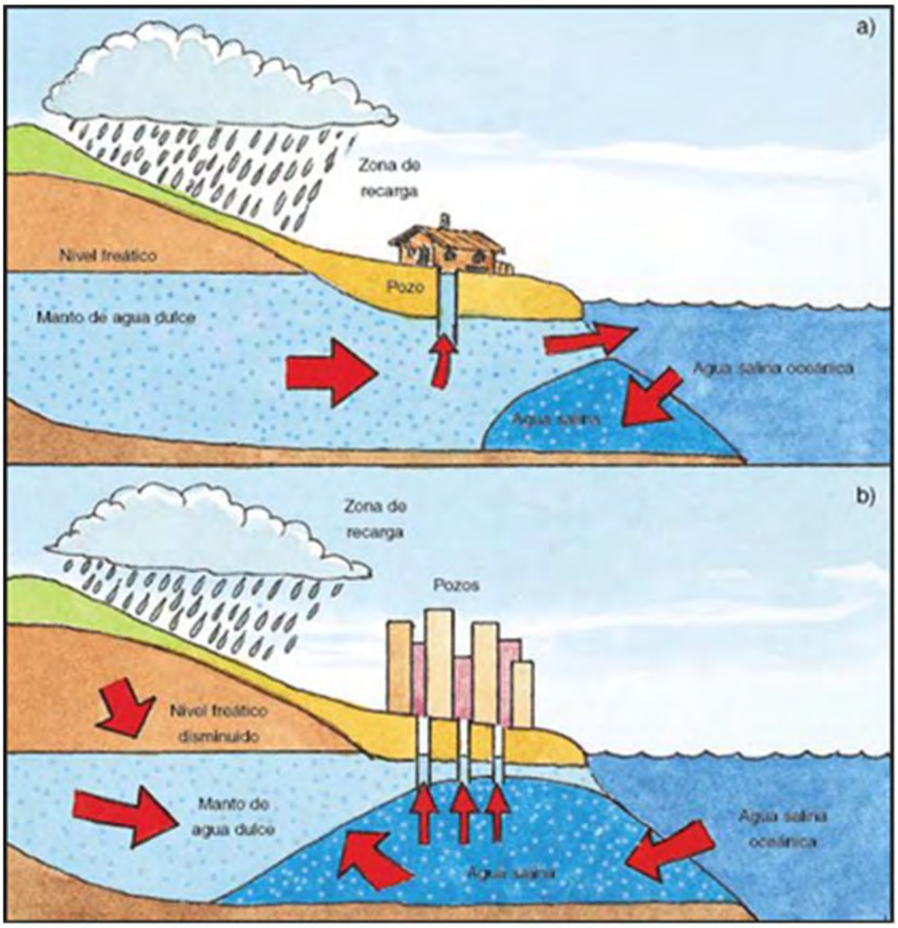

Figure 2-90: Seawater intrusion scheme

b.2 Negative effects of seawater intrusion

The main negative effects of seawater intrusion have an impact on water quality, which could not be consumed for different uses, for human supply or used for agriculture due to:

a)- The increase of seawater intrusion due to the exacerbation of climate change. That is, with the predicted rise in the sea level and/or in certain aquifers close to the coast due to uncontrolled overexploitation, this would raise the levels of elements such as Chlorine, Sodium, sulfates causing:

- Making unsustainable in time the supply of water due to health damages caused by the increase of dissolved salts in the water, thus increasing heart diseases, as well as kidney problems due to salt retention.

- There will be a saturation of salts on the soil, causing their salinization and preventing their use for the scheduled crops, thus having to find productive alternatives which allow sustainable and necessary productions for the consumption of populations.
- Soils in general that are currently cultivated will not be able to produce and there will be great and unpredictable economic losses.

b)- Aspects to be taken into account in the groundwater process of salinization due to seawater intrusion in the aquifers closest to the coast:

- It is important to keep a record of rainfall levels in the areas of influence of each aquifer.
- Maintain a strict control over the deliveries and uses of the amounts of approved water in the water balance, thus avoiding overexploitation, which still persists and ensuring that there is a demand on the productivity of water supplied to agriculture, since they are the largest consumers.
- In the case of the use of water to supply the population or the industry, it is important to foresee the existence of reserve wells that allow a mixture of waters that decrease the salt concentrations and thus ensure their use and the health of the population and the safety of industrial productions.
- It is increasingly important to involve all stakeholders, starting with those responsible for the delivery of water, for different uses and thus avoid leakages and wastes of this vital liquid.
- To maintain an adequate control of water quality monitoring in time and space is becoming an increasingly necessary and important aspect. Specialists, technicians and managers must demand and ensure that they are carried out and analyzed promptly and qualitatively, because the future for further generations will depend on these results.

b.3 Vertical hydrochemical sampling in the Artemisa and Mayabeque provinces

A total of 13 stations were sampled in the period, using the WQC-24 Multiparameter Meter from Japan to determine Temperature, pH, Electrical Conductivity, Turbidity, Salinity and Dissolved Oxygen.

These measurements were made after the arrival of the equipment until April 2016, although in this case only the last values recorded by both provinces appear.

En las páginas siguientes se muestran los resultados de las mediciones efectuadas en forma de tablas para cada uno de los pozos y los gráficos correspondientes destacando los niveles en los cuales el agua comienza a incrementar su salinidad, producto del contacto con el agua salada proveniente de la costa.

The following pages show the results of the measurements made in the form of tables for each of the wells and the corresponding graphs highlighting the levels at which the water begins to increase its salinity, as a result of the contact with the saltwater coming from the coast.

Orientación de los Perfiles. Muestreo Hidroquímico Vertical

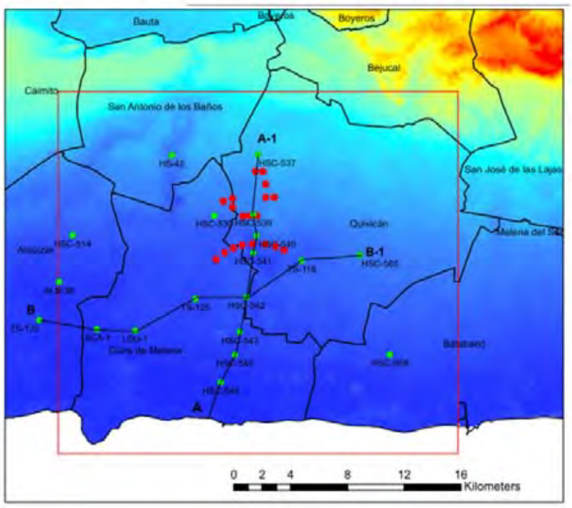

Figure 2-91: Profile Orientation, Vertical Hydrochemical Sampling

In most of the wells studied values between 20 and 40 m below the mean sea level are shown. In this spot height, these wells initiate the increase of the salinity by contact with the sea, that is to say, the g/L is reached and beyond. The wells that were measured are detailed bellow:

Table 2-26: Well coordination

Name	X	Y
JICA-1	340468	324456
LSU-1	343180	324370
HSC-545	350197	322645
HSC-546	349200	320700
TS-125	347400	326610
HSC-543	350541	324258
HSC-542	350997	326746
TS-116	354900	329300
HSC-565	359000	329700
HSC-568	361107	322665
HSC-541	351489	329864
HSC-537	351822	336804
HSC-540	351706	331069

Table 2-27: Results of the measurement in JICA 1

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
JICA-1	340468	324456	28/04/2016	4,0	1,7	55,6	0,2
JICA-1	340468	324456	28/04/2016	6,0	-0,3	53,4	0,2
JICA-1	340468	324456	28/04/2016	10,0	-4,3	74,6	0,3
JICA-1	340468	324456	28/04/2016	12,0	-6,3	104	0,5
JICA-1	340468	324456	28/04/2016	14,0	-8,3	115	0,5
JICA-1	340468	324456	28/04/2016	16,0	-10,3	115	0,5
JICA-1	340468	324456	28/04/2016	18,0	-12,3	116	0,5
JICA-1	340468	324456	28/04/2016	20,0	-14,3	116	0,5
JICA-1	340468	324456	28/04/2016	22,0	-16,3	116	0,5
JICA-1	340468	324456	28/04/2016	25,0	-19,3	1116	0,5
JICA-1	340468	324456	28/04/2016	28,0	-22,3	116	0,5
JICA-1	340468	324456	28/04/2016	30,0	-24,3	116	0,5
JICA-1	340468	324456	28/04/2016	32,0	-26,3	116	0,5
JICA-1	340468	324456	28/04/2016	35,0	-29,3	117	0,5
JICA-1	340468	324456	28/04/2016	38,0	-32,3	117	0,5
JICA-1	340468	324456	28/04/2016	40,0	-34,3	130	0,6
JICA-1	340468	324456	28/04/2016	40,5	-34,8	215	1,1
JICA-1	340468	324456	28/04/2016	43,0	-37,3	2120	13,3
JICA-1	340468	324456	28/04/2016	45,0	-39,3	4250	27,6
JICA-1	340468	324456	28/04/2016	50,0	-44,3	4880	32,3
JICA-1	340468	324456	28/04/2016	52,0	-46,3	4920	32,4
JICA-1	340468	324456	28/04/2016	55,0	-49,3	4920	32,4
JICA-1	340468	324456	28/04/2016	59,0	-53,3	4940	32,8

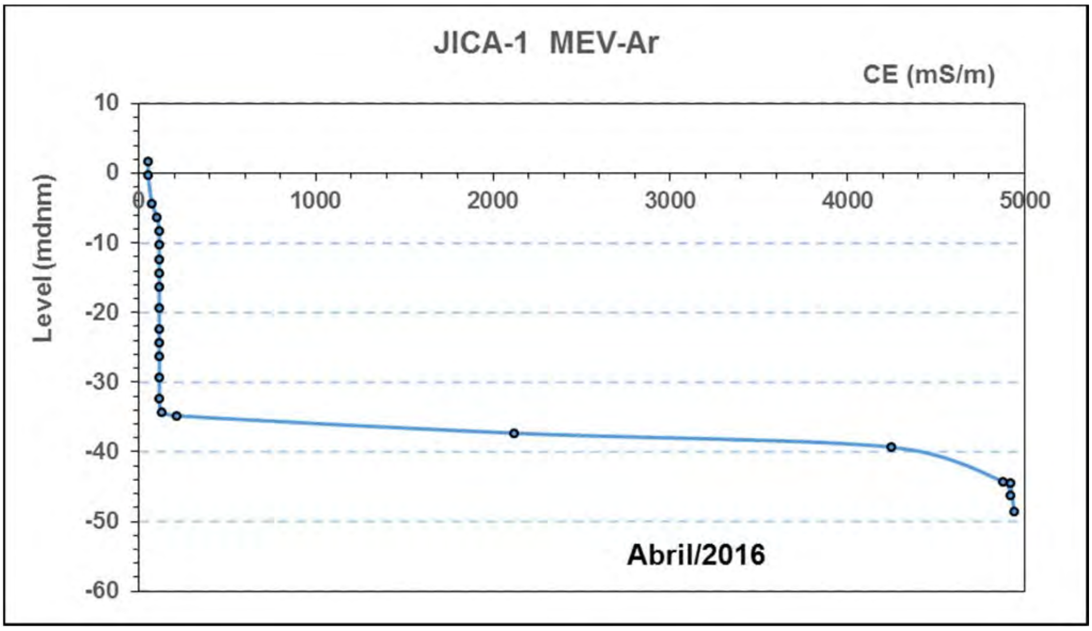

Figure 2-92: Relation between the electrical conductivity (mS /m) and the level of the JICA-1 well

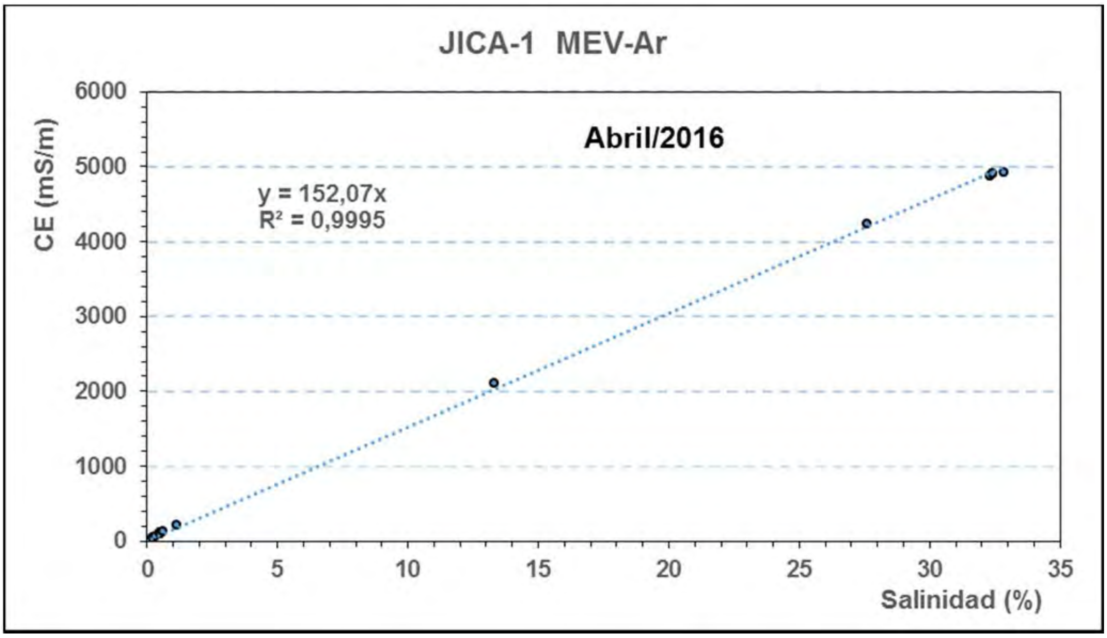

Figure 2-93: Relation between electrical conductivity (mS/m) and salinity (%), JICA-1

Table 2-28: Results of the measurement in LSU-1

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
LSU-1	343180	324370	28/04/2016	4,5	1,0	85	0,4
LSU-1	343180	324370	28/04/2016	8,0	-2,5	85	0,4
LSU-1	343180	324370	28/04/2016	9,0	-3,5	89,8	0,4
LSU-1	343180	324370	28/04/2016	10,0	-4,5	92,1	0,4
LSU-1	343180	324370	28/04/2016	12,0	-6,5	128	0,6
LSU-1	343180	324370	28/04/2016	14,0	-8,5	135	0,6
LSU-1	343180	324370	28/04/2016	16,0	-10,5	135	0,6
LSU-1	343180	324370	28/04/2016	18,0	-12,5	135	0,6
LSU-1	343180	324370	28/04/2016	20,0	-14,5	135	0,6
LSU-1	343180	324370	28/04/2016	22,0	-16,5	135	0,6
LSU-1	343180	324370	28/04/2016	24,0	-18,5	135	0,6
LSU-1	343180	324370	28/04/2016	26,0	-20,5	145	0,7
LSU-1	343180	324370	28/04/2016	27,0	-21,5	151	0,7
LSU-1	343180	324370	28/04/2016	29,0	-23,5	157	0,7
LSU-1	343180	324370	28/04/2016	29,5	-24,0	163	0,8
LSU-1	343180	324370	28/04/2016	30,0	-24,5	164	0,8
LSU-1	343180	324370	28/04/2016	32,0	-26,5	167	0,8
LSU-1	343180	324370	28/04/2016	33,0	-27,5	200	1
LSU-1	343180	324370	28/04/2016	35,0	-29,5	676	3,4
LSU-1	343180	324370	28/04/2016	38,0	-32,5	2180	13,3
LSU-1	343180	324370	28/04/2016	40,0	-34,5	3460	21,7
LSU-1	343180	324370	28/04/2016	42,0	-36,5	4240	27,4

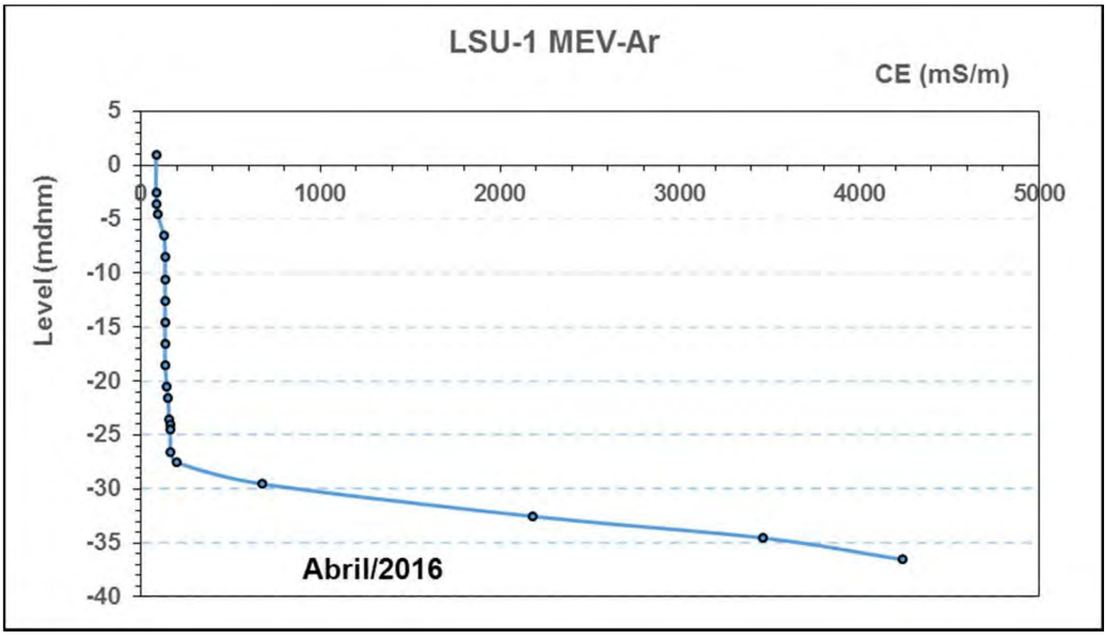

Figure 2-94: Relation between the electrical conductivity (mS/m) and the level of the LSU-1 well

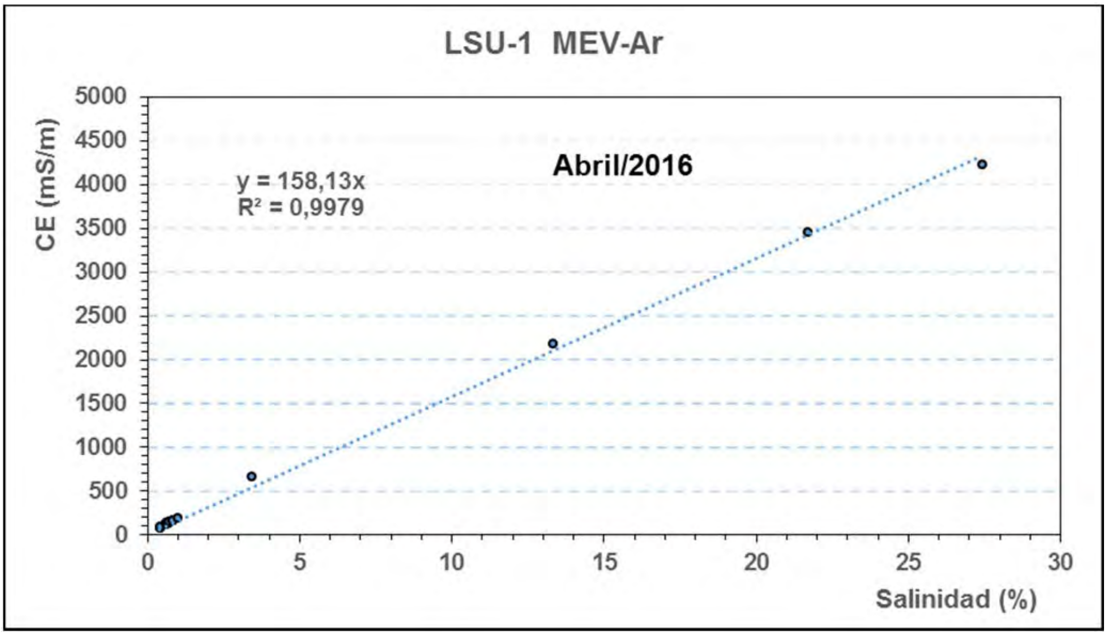

Figure 2-95: Relation between electrical conductivity (mS/m) and salinity (%), LSU-1

Table 2-29: Results of the measurement in HSC-545

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-545	350917	322645	28/04/2016	6,0	-1,8	193	0,9
HSC-545	350917	322645	28/04/2016	7,0	-2,8	192	0,9
HSC-545	350917	322645	28/04/2016	9,0	-4,8	192	0,9
HSC-545	350917	322645	28/04/2016	12,0	-7,8	233	1,2
HSC-545	350917	322645	28/04/2016	14,0	-9,8	296	1,4
HSC-545	350917	322645	28/04/2016	16,0	-11,8	309	1,6
HSC-545	350917	322645	28/04/2016	17,0	-12,8	309	1,6
HSC-545	350917	322645	28/04/2016	19,0	-14,8	459	2,4
HSC-545	350917	322645	28/04/2016	20,0	-15,8	486	2,6
HSC-545	350917	322645	28/04/2016	22,0	-17,8	666	3,6
HSC-545	350917	322645	28/04/2016	25,0	-20,8	950	5,3
HSC-545	350917	322645	28/04/2016	27,0	-22,8	1190	6,9
HSC-545	350917	322645	28/04/2016	29,0	-24,8	1520	8,9
HSC-545	350917	322645	28/04/2016	32,0	-27,8	3000	18,7
HSC-545	350917	322645	28/04/2016	34,0	-29,8	3490	22,2
HSC-545	350917	322645	28/04/2016	36,0	-31,8	4000	25,7
HSC-545	350917	322645	28/04/2016	38,0	-33,8	4450	28,9
HSC-545	350917	322645	28/04/2016	40,0	-35,8	4690	30,6
HSC-545	350917	322645	28/04/2016	42,0	-37,8	4830	31,7

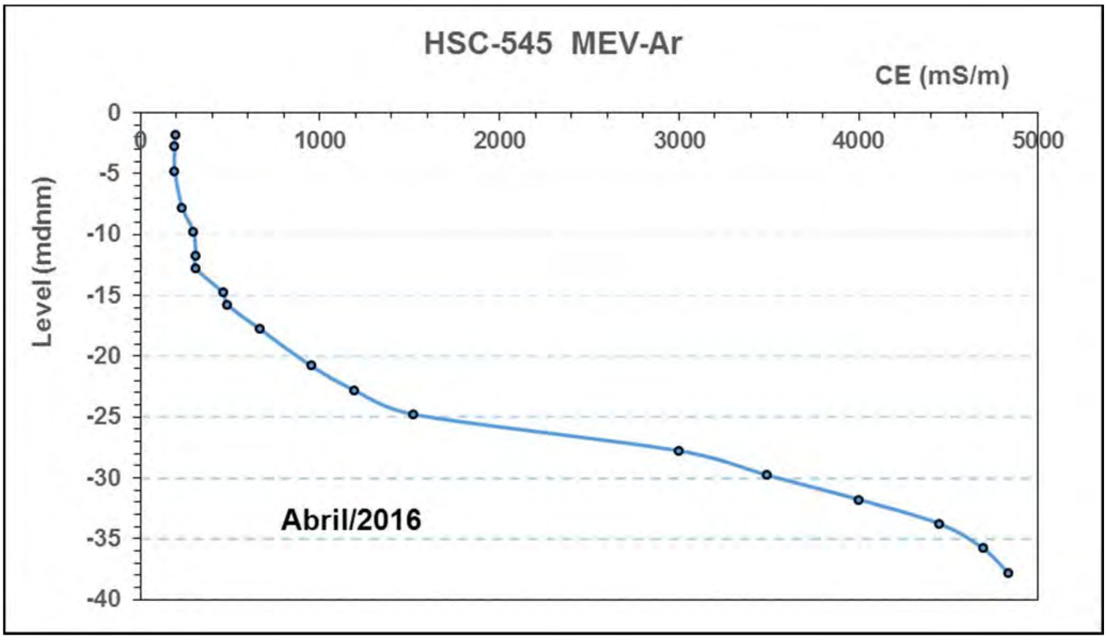

Figure 2-96: Relation between the electrical conductivity (mS/m) and the level of the HSC-545 well

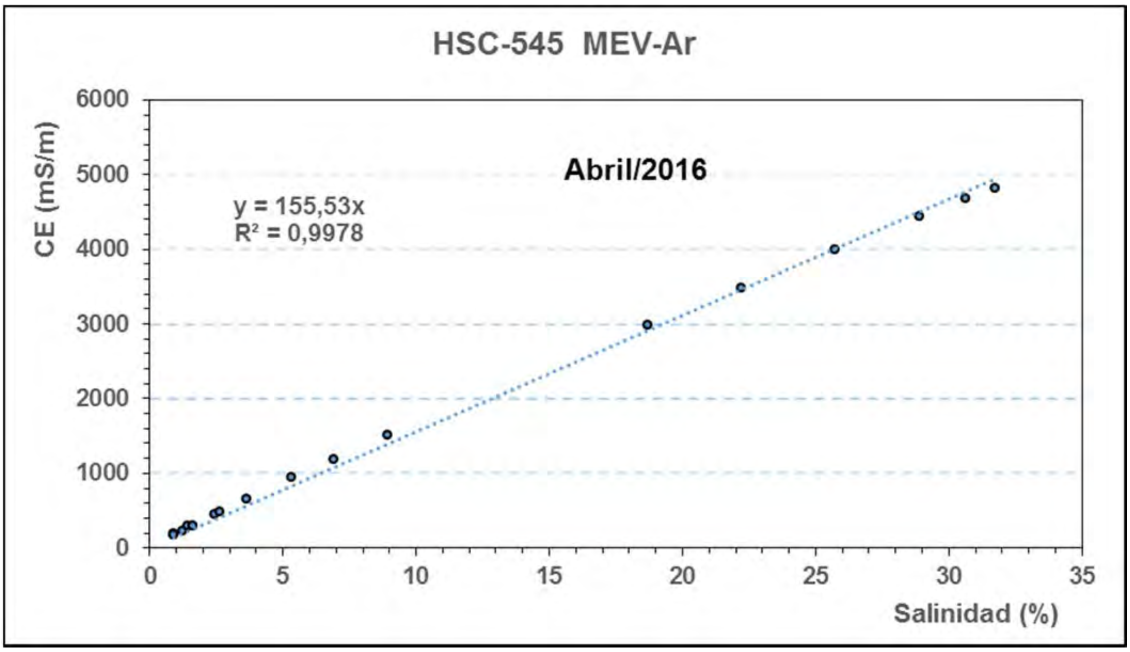

Figure 2-97: Relation between electrical conductivity (mS/m) and salinity (%), HSC-545

Table 2-30: Results of the measurement in HSC-546

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-546	349200	320700	28/04/2016	1,5	0,4	269	1,4
HSC-546	349200	320700	28/04/2016	2,0	-0,1	269	1,4
HSC-546	349200	320700	28/04/2016	4,0	-2,1	269	1,4
HSC-546	349200	320700	28/04/2016	5,0	-3,1	269	1,4
HSC-546	349200	320700	28/04/2016	8,0	-6,1	269	1,4
HSC-546	349200	320700	28/04/2016	11,0	-9,1	649	3,6
HSC-546	349200	320700	28/04/2016	12,0	-10,1	977	5,5
HSC-546	349200	320700	28/04/2016	15,0	-13,1	1400	8,1
HSC-546	349200	320700	28/04/2016	18,0	-16,1	1640	9,7
HSC-546	349200	320700	28/04/2016	20,0	-18,1	1890	11,3
HSC-546	349200	320700	28/04/2016	23,0	-21,1	3290	20,9
HSC-546	349200	320700	28/04/2016	25,0	-23,1	4240	27,4
HSC-546	349200	320700	28/04/2016	30,0	-28,1	4620	30,2
HSC-546	349200	320700	28/04/2016	33,0	-31,1	4700	30,7
HSC-546	349200	320700	28/04/2016	34,0	-32,1	4700	30,8

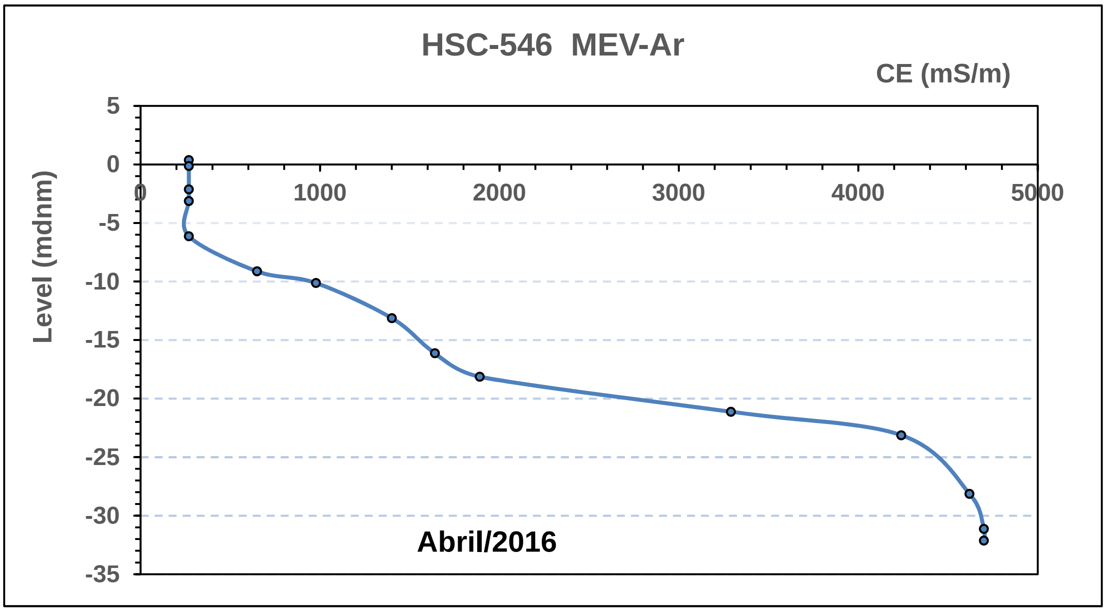

Figure 2-98: Relation between the electrical conductivity (mS/m) and the level of the HSC-546 well

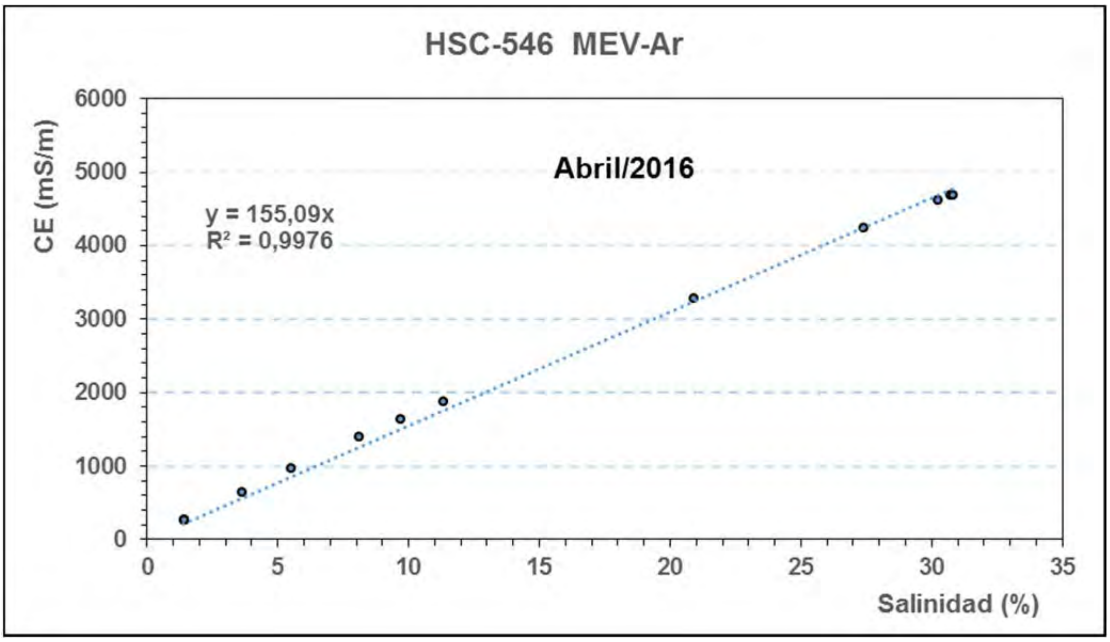

Figure 2-99: Relation between electrical conductivity (mS/m) and salinity (%), HSC-546

Table 2-31: Results of the measurement in TS-125

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
TS-125	347400	326610	28/04/2016	10,0	-1,4	78,3	0,3
TS-125	347400	326610	28/04/2016	12,0	-3,4	78,3	0,3
TS-125	347400	326610	28/04/2016	15,0	-6,4	78,3	0,3
TS-125	347400	326610	28/04/2016	18,0	-9,4	78,3	0,3
TS-125	347400	326610	28/04/2016	20,0	-11,4	78,2	0,3
TS-125	347400	326610	28/04/2016	22,0	-13,4	78,4	0,3
TS-125	347400	326610	28/04/2016	24,0	-15,4	78,5	0,3
TS-125	347400	326610	28/04/2016	26,0	-17,4	78,8	0,3
TS-125	347400	326610	28/04/2016	29,0	-20,4	80,2	0,3
TS-125	347400	326610	28/04/2016	32,0	-23,4	96,5	0,4
TS-125	347400	326610	28/04/2016	33,0	-24,4	111	0,5
TS-125	347400	326610	28/04/2016	35,0	-26,4	162	0,5
TS-125	347400	326610	28/04/2016	36,0	-27,4	178	0,9
TS-125	347400	326610	28/04/2016	37,4	-28,8	178	0,9

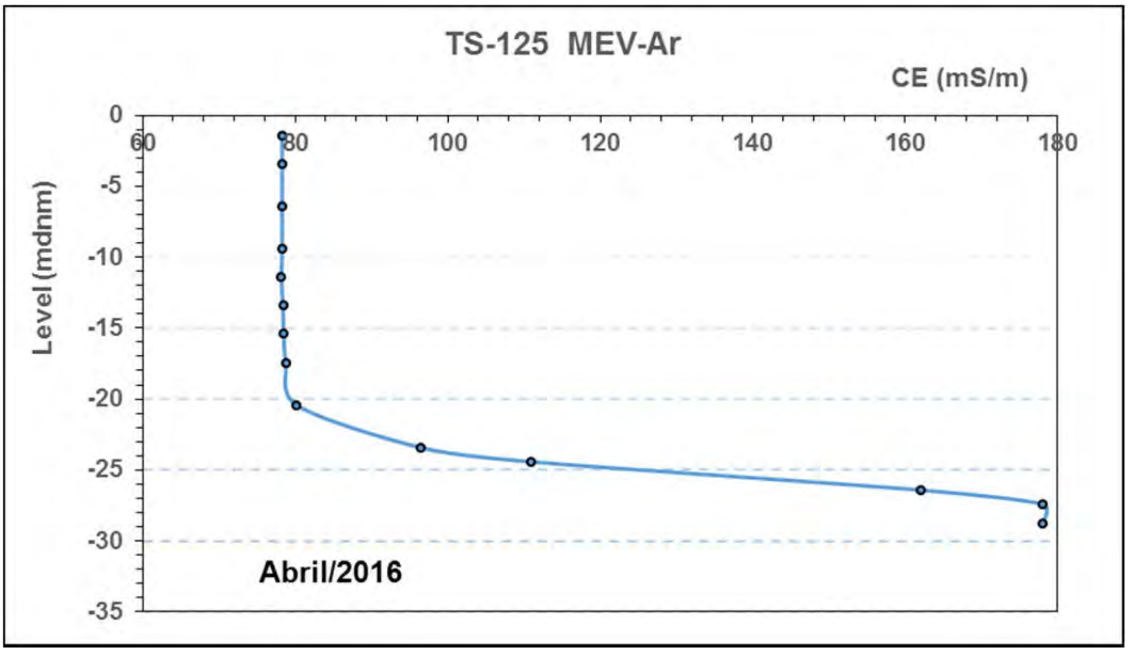

Figure 2-100: Relation between the electrical conductivity (mS/m) and the level of the TS-125 well

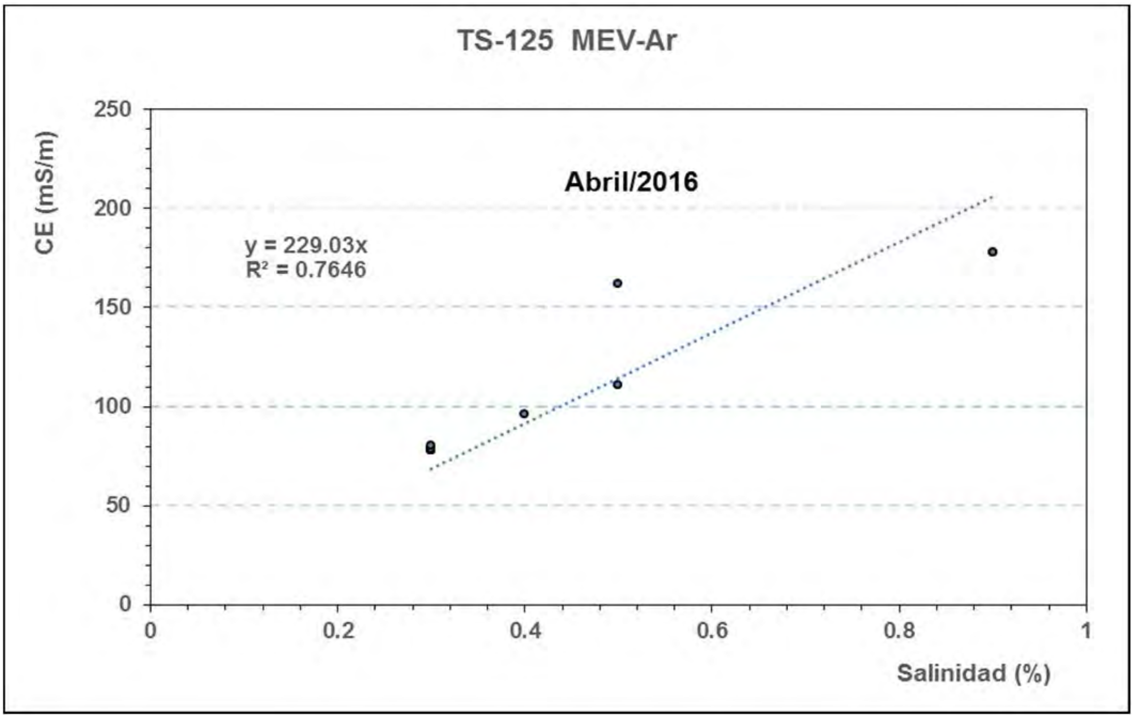

Figure 2-101: Relation between electrical conductivity (mS/m) and salinity (%), TS-125

Table 2-32: Results of the measurement in HSC-543

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-543	350541	324258	28/04/2016	10,0	-2,5	25,1	0,1
HSC-543	350541	324258	28/04/2016	11,0	-3,5	24,9	0,1
HSC-543	350541	324258	28/04/2016	15,0	-7,5	24,4	0,1
HSC-543	350541	324258	28/04/2016	18,0	-10,5	24,3	0,1
HSC-543	350541	324258	28/04/2016	20,0	-12,5	24,4	0,1
HSC-543	350541	324258	28/04/2016	24,0	-16,5	24,5	0,1
HSC-543	350541	324258	28/04/2016	26,0	-18,5	24,4	0,1
HSC-543	350541	324258	28/04/2016	29,0	-21,5	24,1	0,1
HSC-543	350541	324258	28/04/2016	32,0	-24,5	23,9	0,1
HSC-543	350541	324258	28/04/2016	35,0	-27,5	23,5	0,1
HSC-543	350541	324258	28/04/2016	38,0	-30,5	23,7	0,1
HSC-543	350541	324258	28/04/2016	40,0	-32,5	23,7	0,1

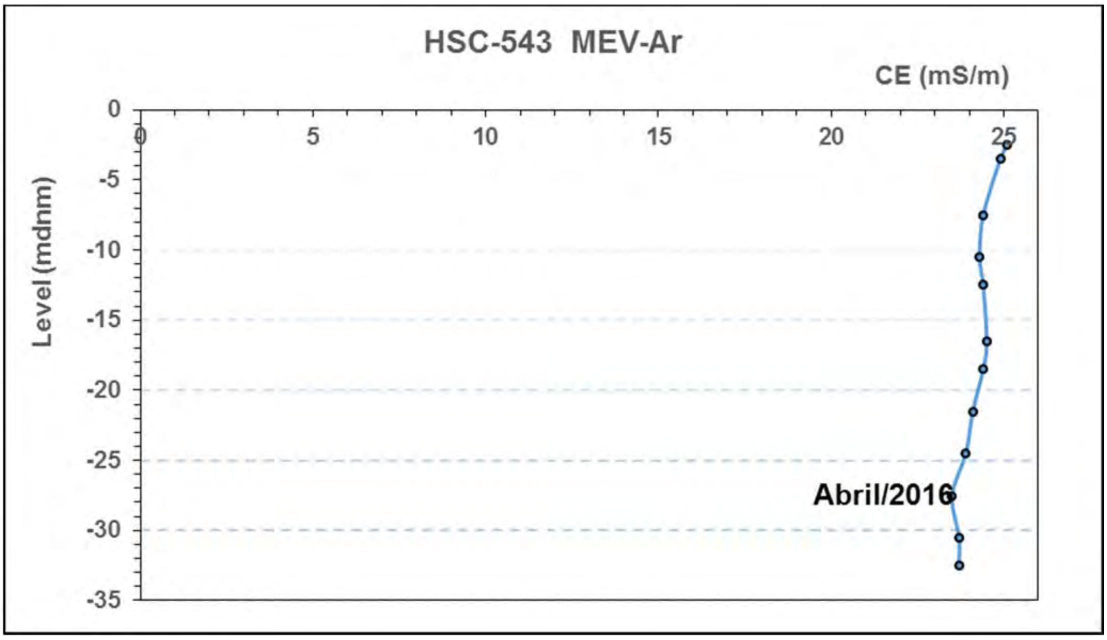

Figure 2-102: Relation between the electrical conductivity (mS/m) and the level of the HSC-543 well

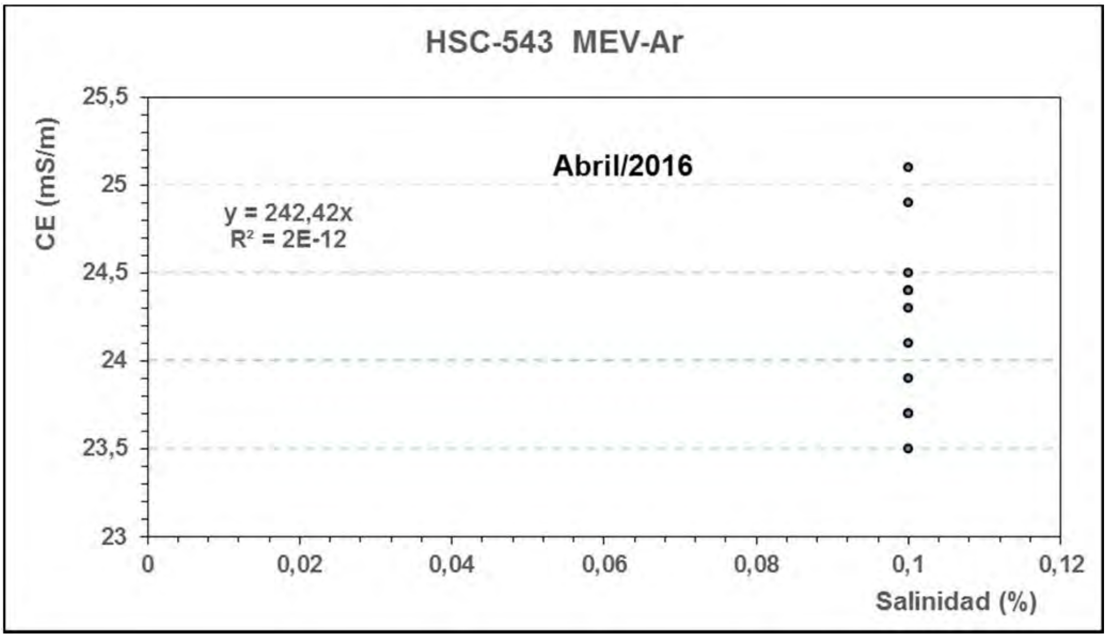

Figure 2-103: Relation between electrical conductivity (mS/m) and salinity (%), HSC-543

Table 2-33: Results of the measurement in HSC-542

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-542	350997	326746	28/04/2016	11,0	-0,5	88,4	0,4
HSC-542	350997	326746	28/04/2016	12,0	-1,5	86,4	0,4
HSC-542	350997	326746	28/04/2016	13,0	-2,5	86,4	0,4
HSC-542	350997	326746	28/04/2016	14,0	-3,5	87,1	0,4
HSC-542	350997	326746	28/04/2016	15,0	-4,5	87,6	0,4
HSC-542	350997	326746	28/04/2016	16,0	-5,5	87,9	0,4
HSC-542	350997	326746	28/04/2016	18,0	-7,5	88,1	0,4
HSC-542	350997	326746	28/04/2016	20,0	-9,5	88,2	0,4
HSC-542	350997	326746	28/04/2016	22,0	-11,5	89,1	0,4
HSC-542	350997	326746	28/04/2016	24,0	-13,5	99,1	0,4
HSC-542	350997	326746	28/04/2016	26,0	-15,5	99,1	0,4
HSC-542	350997	326746	28/04/2016	28,0	-17,5	106	0,5
HSC-542	350997	326746	28/04/2016	30,0	-19,5	107	0,5
HSC-542	350997	326746	28/04/2016	32,0	-21,5	108	0,5
HSC-542	350997	326746	28/04/2016	34,0	-23,5	111	0,5
HSC-542	350997	326746	28/04/2016	36,0	-25,5	115	0,5
HSC-542	350997	326746	28/04/2016	36,5	-26,0	127	0,6
HSC-542	350997	326746	28/04/2016	37,0	-26,5	155	0,7
HSC-542	350997	326746	28/04/2016	37,1	--26,6	187	0,9
HSC-542	350997	326746	28/04/2016	37,3	-26,8	209	1
HSC-542	350997	326746	28/04/2016	39,0	-28,5	437	2,3
HSC-542	350997	326746	28/04/2016	42,0	-31,5	1250	7,2
HSC-542	350997	326746	28/04/2016	44,0	-33,5	2250	13,7
HSC-542	350997	326746	28/04/2016	46,0	-35,5	4140	26,9
HSC-542	350997	326746	28/04/2016	48,0	-37,5	4560	29,8
HSC-542	350997	326746	28/04/2016	50,0	-39,5	4890	32,2
HSC-542	350997	326746	28/04/2016	52,0	-41,5	4900	32,3
HSC-542	350997	326746	28/04/2016	55,0	-44,5	4900	32,6
HSC-542	350997	326746	28/04/2016	60,0	-49,5	4900	32,8

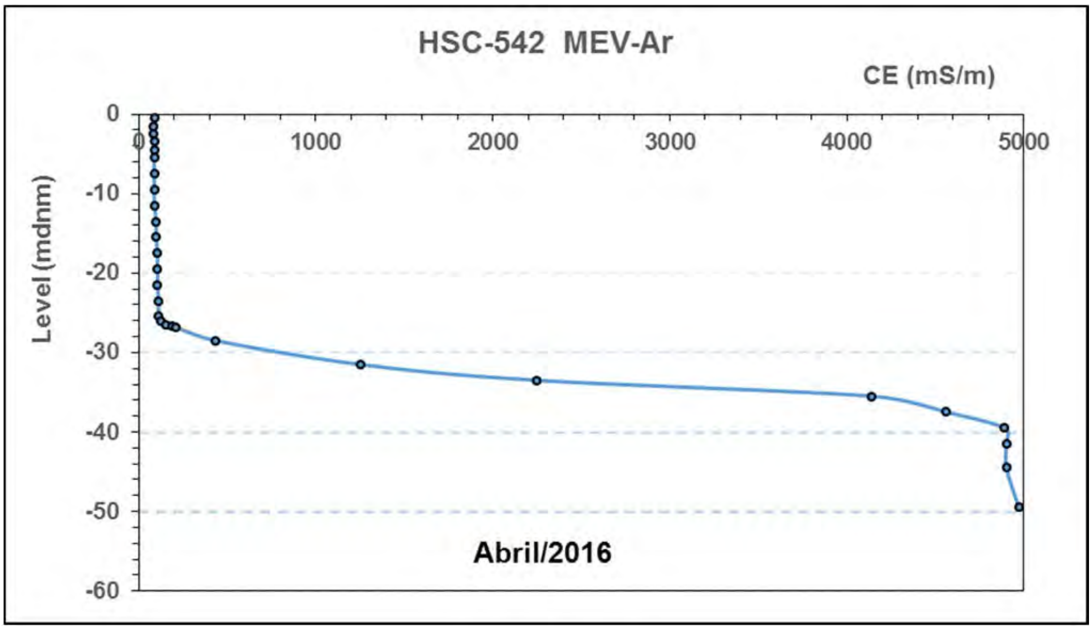

Figure 2-104: Relation between the electrical conductivity (mS/m) and the level of the HSC-542 well

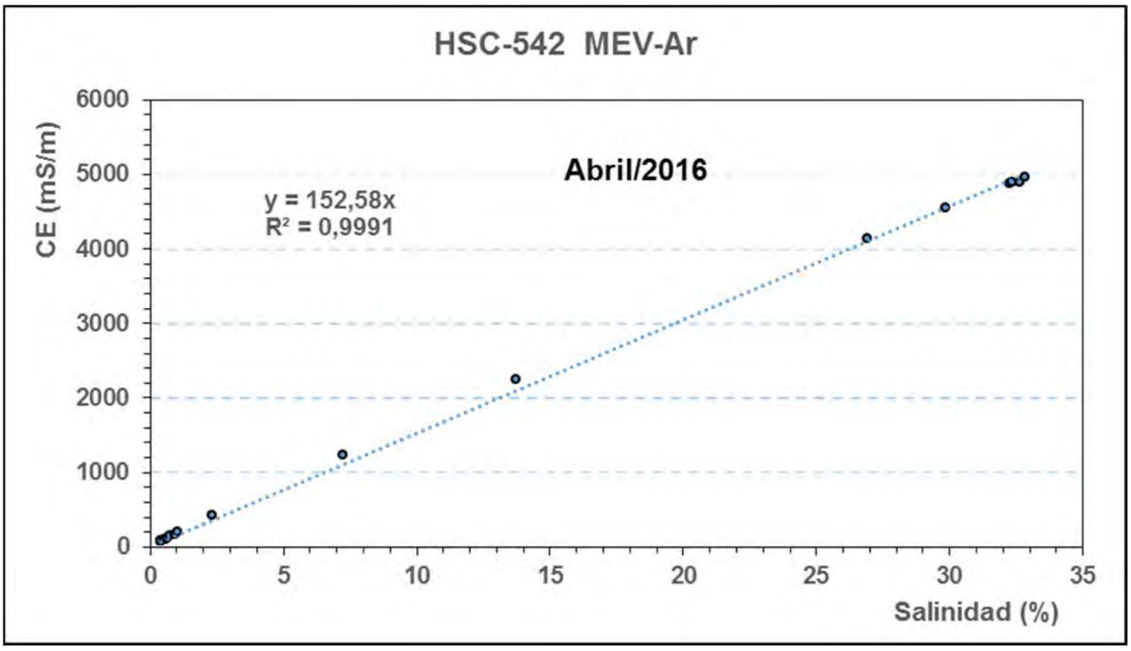

Figure 2-105: Relation between electrical conductivity (mS/m) and salinity (%), HSC-542

Table 2-34: Results of the measurement in TS-116

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
TS-116	354900	329300	28/04/2016	15,8	0,9	71,6	0,3
TS-116	354900	329300	28/04/2016	19,8	-3,1	71,0	0,3
TS-116	354900	329300	28/04/2016	23,8	-7,1	70,8	0,3
TS-116	354900	329300	28/04/2016	27,8	-11,1	70,3	0,3
TS-116	354900	329300	28/04/2016	31,8	-15,1	69,9	0,3
TS-116	354900	329300	28/04/2016	35,8	-19,1	76,0	0,3
TS-116	354900	329300	28/04/2016	39,8	-23,1	76,5	0,3
TS-116	354900	329300	28/04/2016	43,8	-27,1	76,2	0,3
TS-116	354900	329300	28/04/2016	47,8	-31,1	76,1	0,3
TS-116	354900	329300	28/04/2016	51,0	-34,3	138	1
TS-116	354900	329300	28/04/2016	51,8	-35,1	664	3,6
TS-116	354900	329300	28/04/2016	53,8	-37,1	1350	7,9
TS-116	354900	329300	28/04/2016	55,8	-39,1	2260	13,9
TS-116	354900	329300	28/04/2016	57,8	-41,1	3410	21,6
TS-116	354900	329300	28/04/2016	59,8	-43,1	3800	24,3
TS-116	354900	329300	28/04/2016	61,8	-45,1	3990	25,7
TS-116	354900	329300	28/04/2016	63,8	-47,1	4320	29,6
TS-116	354900	329300	28/04/2016	64,8	-48,1	4710	30,9
TS-116	354900	329300	28/04/2016	65,8	-49,1	4850	31,9
TS-116	354900	329300	28/04/2016	66,8	-50,1	4910	32,4
TS-116	354900	329300	28/04/2016	67,8	-51,1	5030	33,5

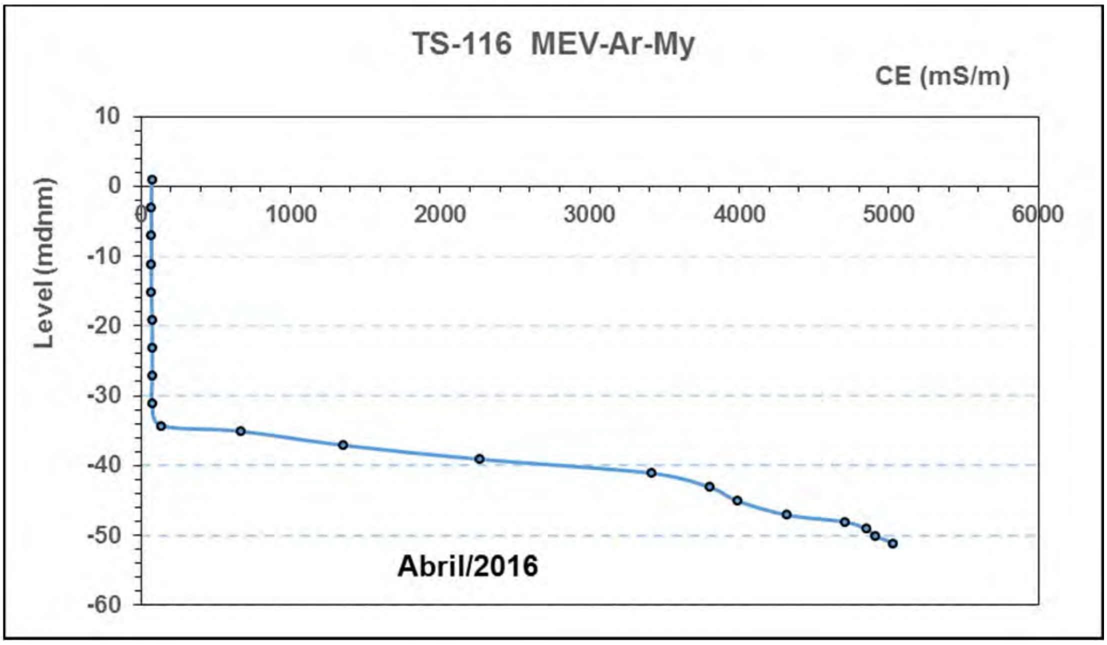

Figure 2-106: Relation between the electrical conductivity (mS/m) and the level of the TS-116 well

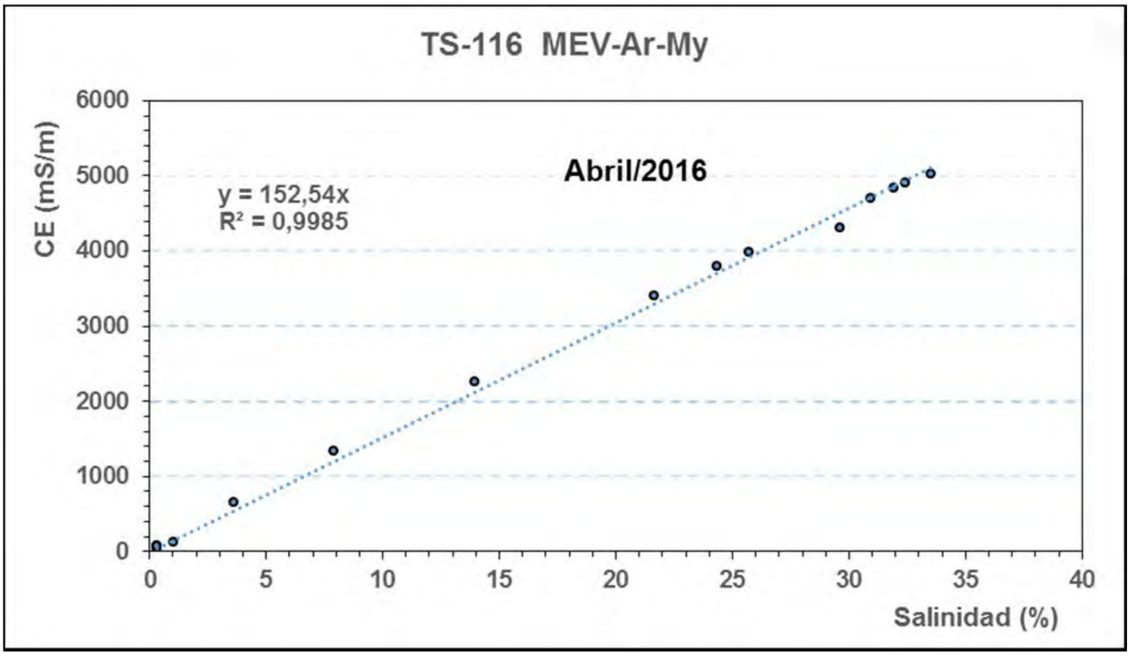

Figure 2-107: Relation between electrical conductivity (mS/m) and salinity (%), TS-116

Table 2-35: Results of the measurement in HSC-565

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-565	359000	329700	28/04/2016	25,7	2,2	116	0,6
HSC-565	359000	329700	28/04/2016	29,7	-1,8	116	0,6
HSC-565	359000	329700	28/04/2016	33,7	-5,8	180	0,6
HSC-565	359000	329700	28/04/2016	37,7	-9,8	150	0,6
HSC-565	359000	329700	28/04/2016	41,7	-13,8	156	0,6
HSC-565	359000	329700	28/04/2016	45,7	-17,8	160	0,7
HSC-565	359000	329700	28/04/2016	49,7	-21,8	155	0,7
HSC-565	359000	329700	28/04/2016	53,7	-25,8	180	0,9
HSC-565	359000	329700	28/04/2016	57,7	-29,8	185	0,9
HSC-565	359000	329700	28/04/2016	61,7	-33,8	190	0,8
HSC-565	359000	329700	28/04/2016	65,7	-37,8	178	0,8
HSC-565	359000	329700	28/04/2016	69,7	-41,8	175	0,9
HSC-565	359000	329700	28/04/2016	73,7	-45,8	171	0,9
HSC-565	359000	329700	28/04/2016	76,7	-48,9	230	1
HSC-565	359000	329700	28/04/2016	78,7	-50,8	250	1,6
HSC-565	359000	329700	28/04/2016	80,7	-52,8	280	22,6
HSC-565	359000	329700	28/04/2016	82,7	-54,8	3340	29
HSC-565	359000	329700	28/04/2016	84,7	-56,8	3390	29,8
HSC-565	359000	329700	28/04/2016	86,5	-58,6	4510	30,2
HSC-565	359000	329700	28/04/2016	88,7	-60,8	4580	30,6
HSC-565	359000	329700	28/04/2016	90,7	-62,8	4580	30,6

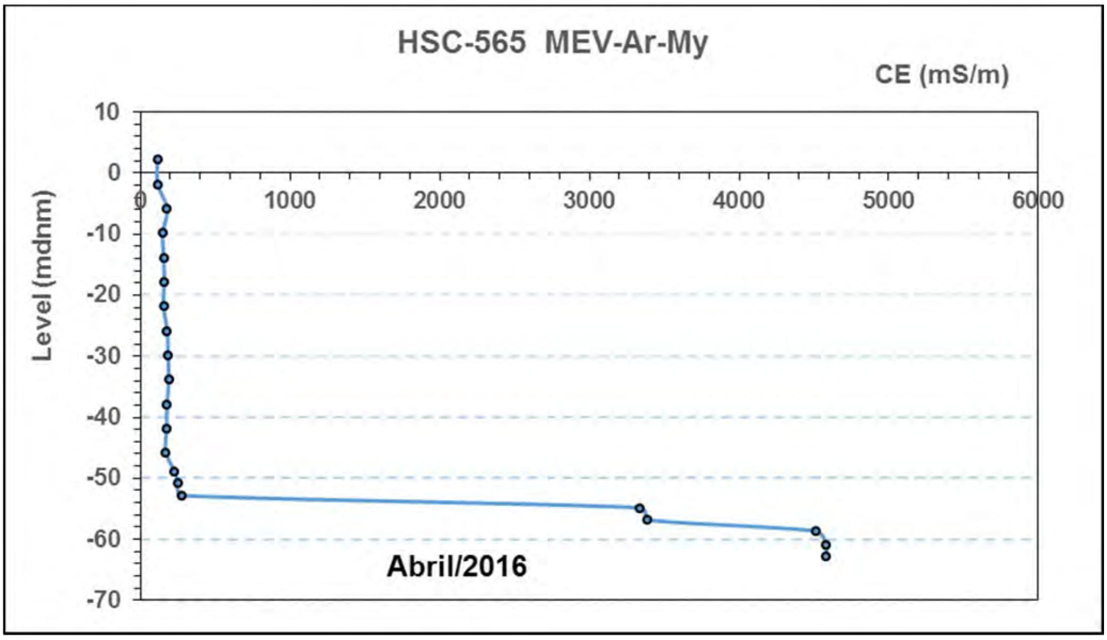

Figure 2-108: Relation between the electrical conductivity (mS/m) and the level of the HSC-565 well

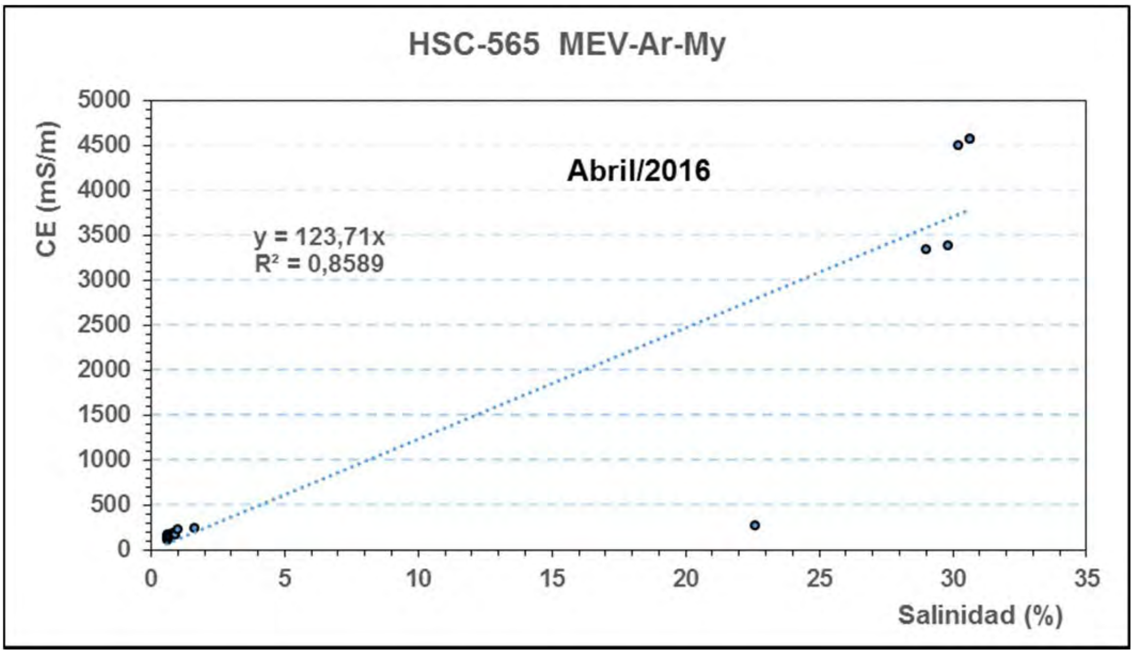

Figure 2-109: Relation between electrical conductivity (mS/m) and salinity (%), HSC-565

Table 2-36: Results of the measurement in HSC-568

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-568	361107	322665	28/04/2016	8,9	0,0	167	0,6
HSC-568	361107	322665	28/04/2016	10,9	-2,0	167	0,8
HSC-568	361107	322665	28/04/2016	12,9	-4,0	176	0,9
HSC-568	361107	322665	28/04/2016	14,9	-6,0	187	0,9
HSC-568	361107	322665	28/04/2016	16,9	-8,0	198	1
HSC-568	361107	322665	28/04/2016	20,9	-12,0	197	1
HSC-568	361107	322665	28/04/2016	24,9	-16,0	174	0,9
HSC-568	361107	322665	28/04/2016	28,9	-20,0	160	0,8
HSC-568	361107	322665	28/04/2016	32,9	-24,0	209	1
HSC-568	361107	322665	28/04/2016	36,9	-28,0	508	2,6
HSC-568	361107	322665	28/04/2016	40,9	-32,0	1500	8,7
HSC-568	361107	322665	28/04/2016	44,9	-36,0	3010	18,8
HSC-568	361107	322665	28/04/2016	48,9	-40,0	3290	20,7
HSC-568	361107	322665	28/04/2016	52,9	-44,0	3310	20,9
HSC-568	361107	322665	28/04/2016	56,9	-48,0	3310	20,9
HSC-568	361107	322665	28/04/2016	60,9	-52,0	3310	20,5

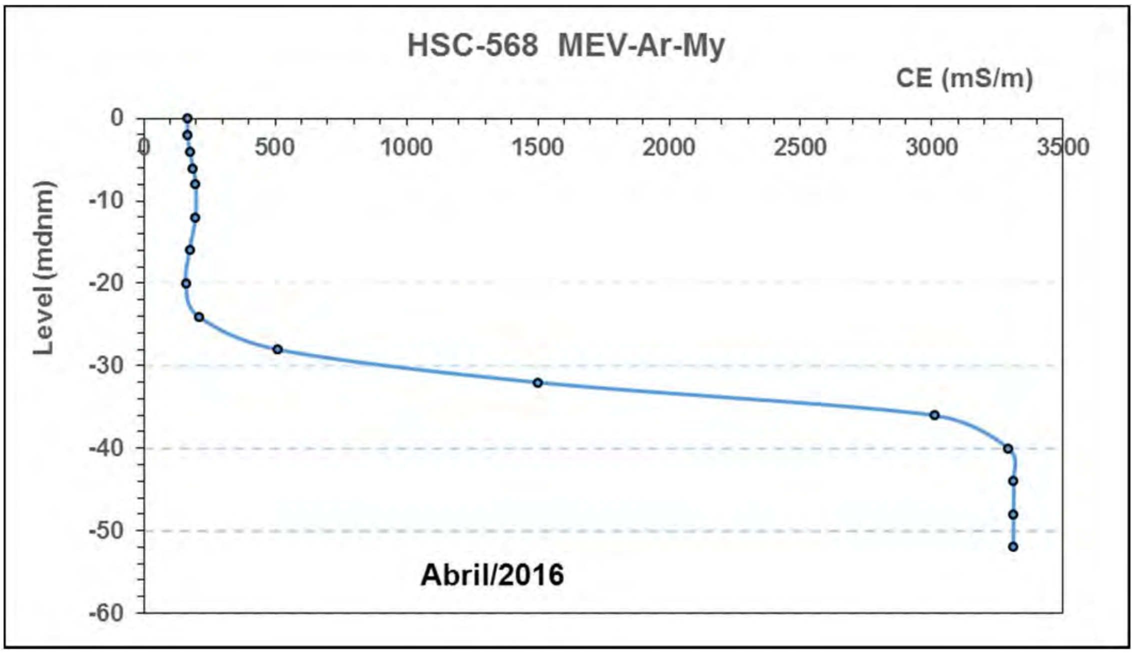

Figure 2-110: Relation between the electrical conductivity (mS/m) and the level of the HSC-568 well

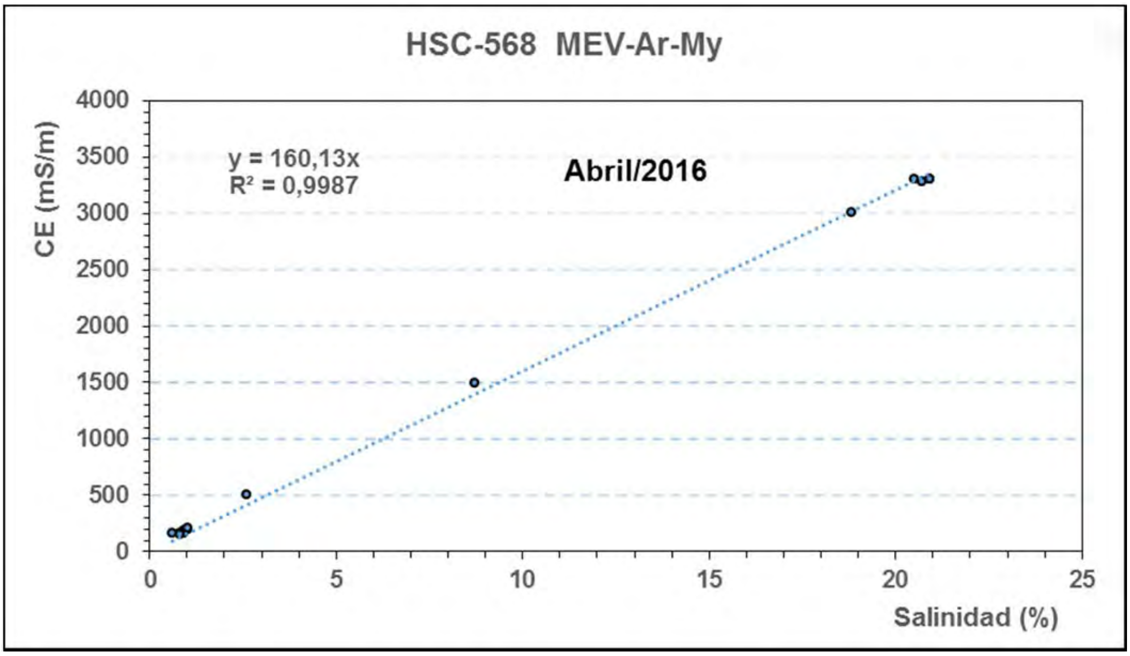

Figure 2-111: Relation between electrical conductivity (mS/m) and salinity (%), HSC-568

Table 2-37: Results of the measurement in HSC-541

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-541	351489	329864	28/04/2016	6,0	0,7	63,9	0,3
HSC-541	351489	329864	28/04/2016	10,0	-3,3	68,5	0,3
HSC-541	351489	329864	28/04/2016	14,0	-7,3	68,0	0,3
HSC-541	351489	329864	28/04/2016	18,0	-11,3	67,5	0,3
HSC-541	351489	329864	28/04/2016	20,0	-13,3	65,5	0,3
HSC-541	351489	329864	28/04/2016	24,0	-17,3	67,9	0,3
HSC-541	351489	329864	28/04/2016	28,0	-21,3	71,0	0,3
HSC-541	351489	329864	28/04/2016	31,1	-24,4	309	1
HSC-541	351489	329864	28/04/2016	32,0	-25,3	663	3,5
HSC-541	351489	329864	28/04/2016	34,0	-27,3	1400	8,2
HSC-541	351489	329864	28/04/2016	36,0	-29,3	2180	13,2
HSC-541	351489	329864	28/04/2016	38,0	-31,3	3020	18
HSC-541	351489	329864	28/04/2016	40,0	-33,3	3750	23,9
HSC-541	351489	329864	28/04/2016	42,0	-35,3	4100	26,5
HSC-541	351489	329864	28/04/2016	44,0	-37,3	4630	30
HSC-541	351489	329864	28/04/2016	45,0	-38,3	4740	31
HSC-541	351489	329864	28/04/2016	46,0	-39,3	4820	31,6

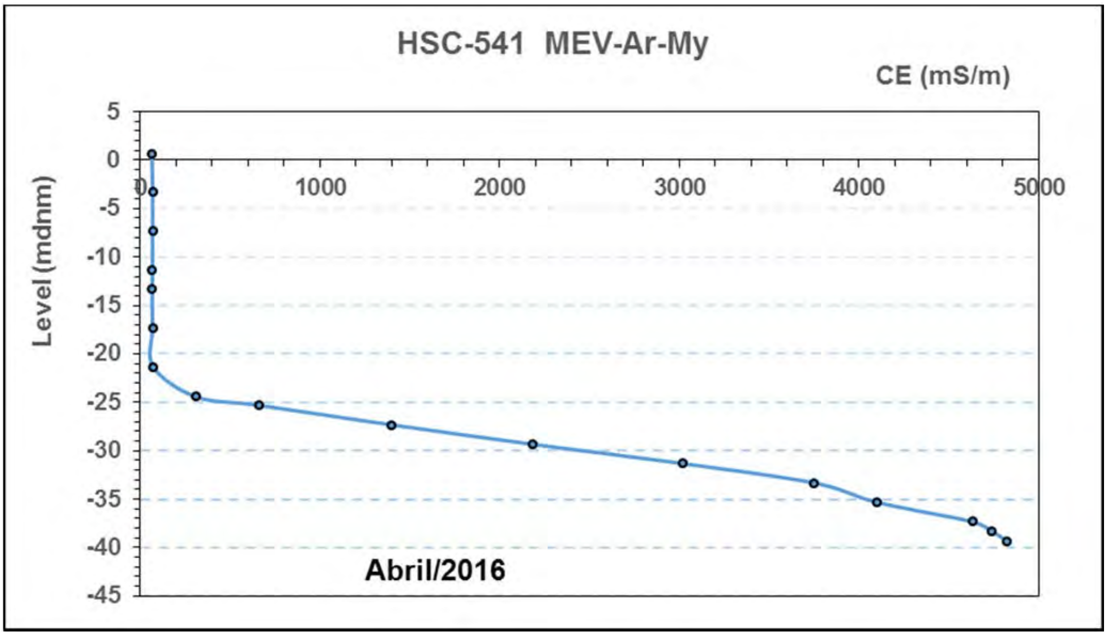

Figure 2-112: Relation between the electrical conductivity (mS/m) and the level of the HSC-541 well

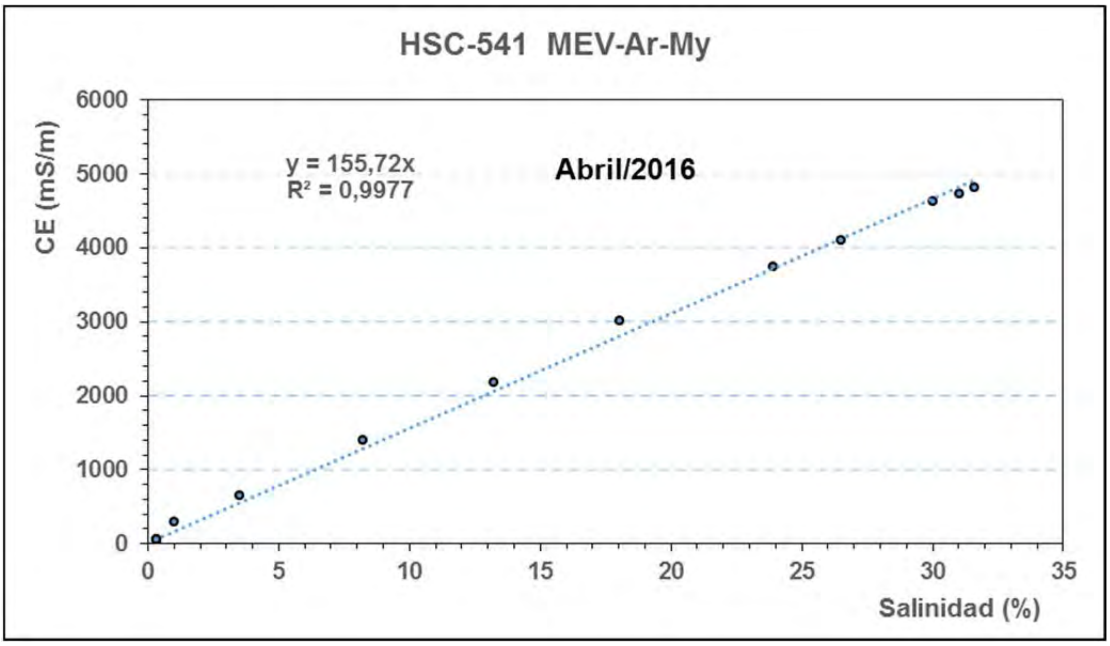

Figure 2-113: Relation between electrical conductivity (mS/m) and salinity (%), HSC-541

Table 2-38: Results of the measurement in HSC-537

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-537	351822	336804	28/04/2016	47,7	1,1	73,3	0,3
HSC-537	351822	336804	28/04/2016	51,7	-2,9	72,6	0,3
HSC-537	351822	336804	28/04/2016	55,7	-6,9	72,5	0,3
HSC-537	351822	336804	28/04/2016	59,7	-10,9	72,8	0,3
HSC-537	351822	336804	28/04/2016	63,7	-14,9	73,8	0,3
HSC-537	351822	336804	28/04/2016	67,7	-18,9	73,8	0,3
HSC-537	351822	336804	28/04/2016	71,7	-22,9	81,2	0,4
HSC-537	351822	336804	28/04/2016	72,1	-23,4	160	1
HSC-537	351822	336804	28/04/2016	72,7	-23,9	283	1,4
HSC-537	351822	336804	28/04/2016	75,7	-26,9	292	1,5
HSC-537	351822	336804	28/04/2016	79,7	-30,9	304	1,5

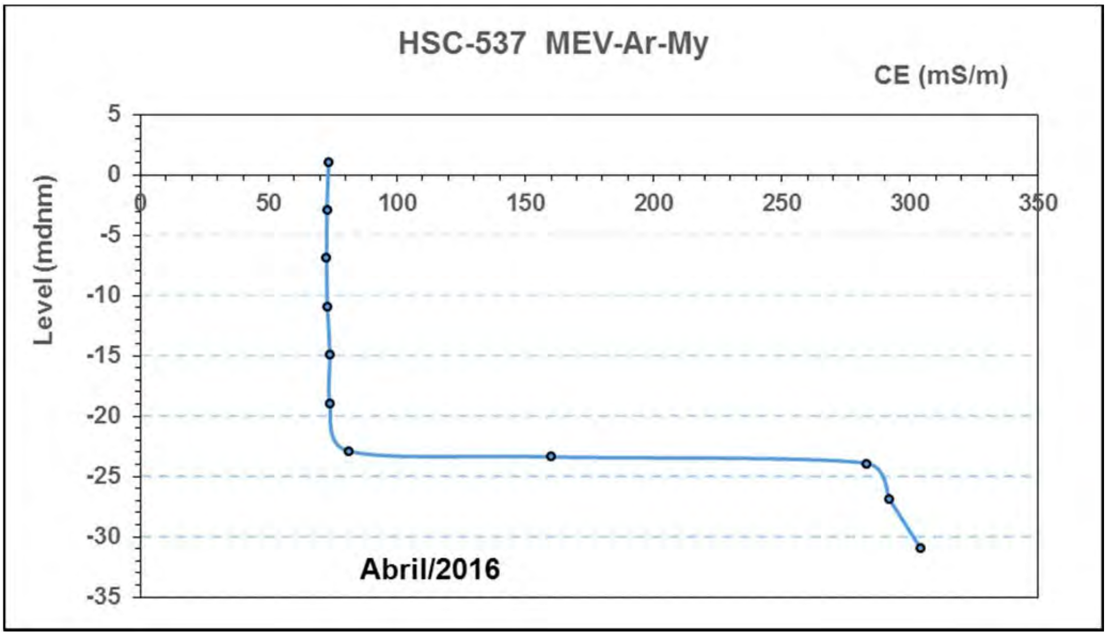

Figure 2-114: Relation between the electrical conductivity (mS/m) and the level of the HSC-537 well

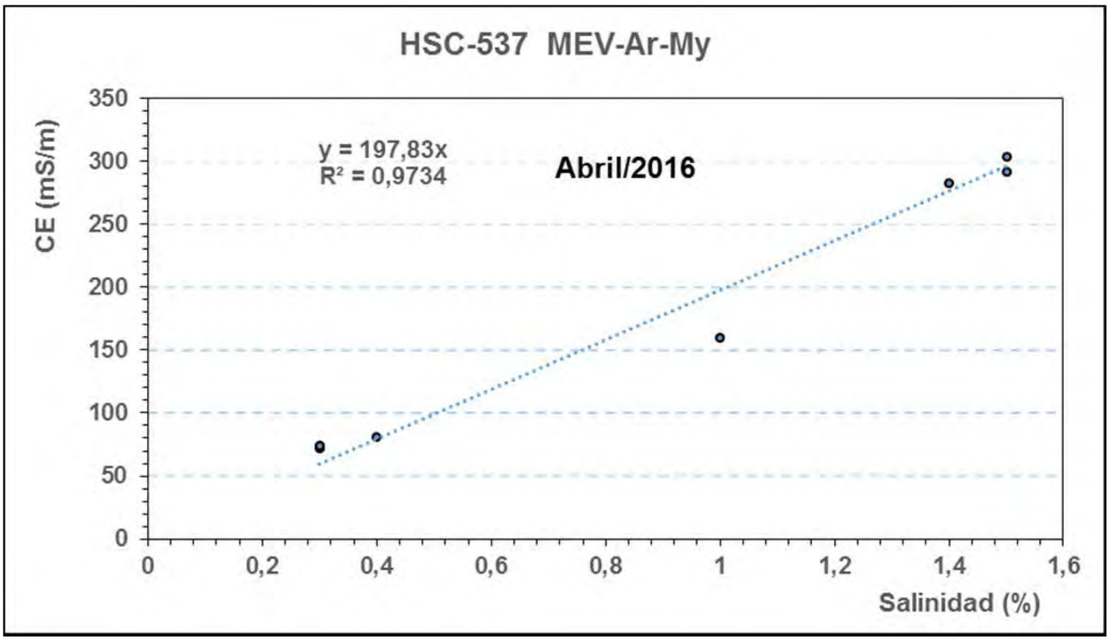

Figure 2-115: Relation between electrical conductivity (mS/m) and salinity (%), HSC-537

Table 2-39: Results of the measurement in HSC-540

Name	X	Y	Date	Depth (m)	Elevation (mamsl)	EC (mS/m)	Salinity (%)
HSC-540	351706	331069	28/04/2016	17,7	0,0	64,4	0,3
HSC-540	351706	331069	28/04/2016	21,7	-4,0	63,6	0,3
HSC-540	351706	331069	28/04/2016	25,7	-8,0	64,5	0,3
HSC-540	351706	331069	28/04/2016	29,7	-12,0	68,3	0,3
HSC-540	351706	331069	28/04/2016	33,7	-16,0	69,1	0,3
HSC-540	351706	331069	28/04/2016	37,7	-20,0	71,7	0,3
HSC-540	351706	331069	28/04/2016	41,7	-24,0	72,9	0,3
HSC-540	351706	331069	28/04/2016	44,5	-26,8	197	1
HSC-540	351706	331069	28/04/2016	44,7	-27,0	234	1,2
HSC-540	351706	331069	28/04/2016	46,7	-29,0	363	1,9
HSC-540	351706	331069	28/04/2016	48,7	-31,0	795	4,5
HSC-540	351706	331069	28/04/2016	50,7	-33,0	2080	12,8
HSC-540	351706	331069	28/04/2016	52,7	-35,0	3050	19,1
HSC-540	351706	331069	28/04/2016	54,7	-37,0	4140	28,0
HSC-540	351706	331069	28/04/2016	56,7	-39,0	4800	31,5
HSC-540	351706	331069	28/04/2016	57,7	-40,0	4910	32,3

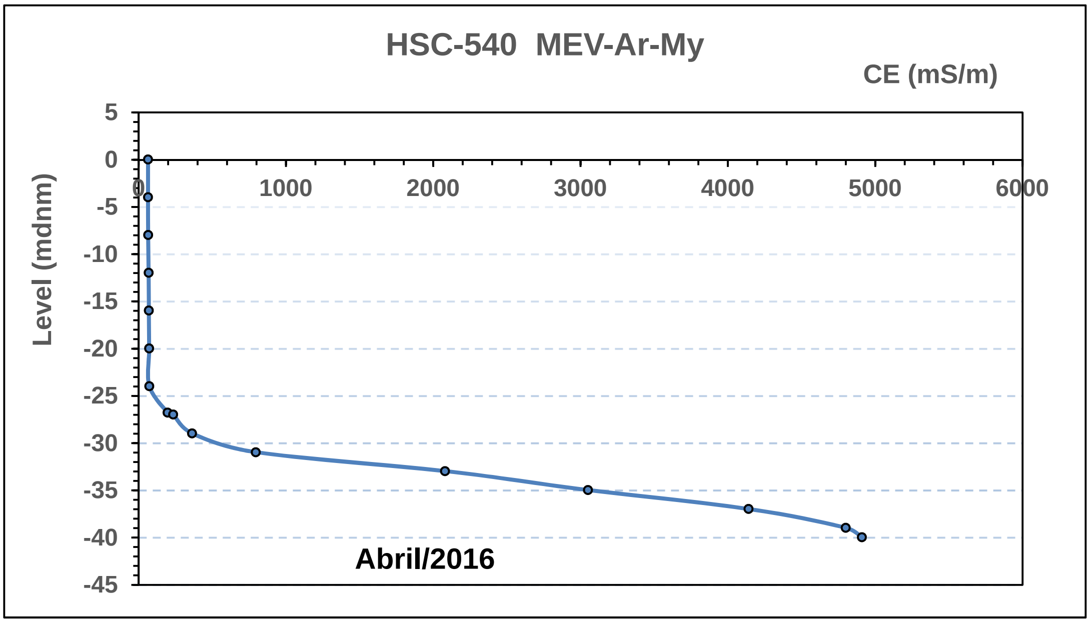

Figure 2-116: Relation between the electrical conductivity (mS/m) and the level of the HSC-540 well

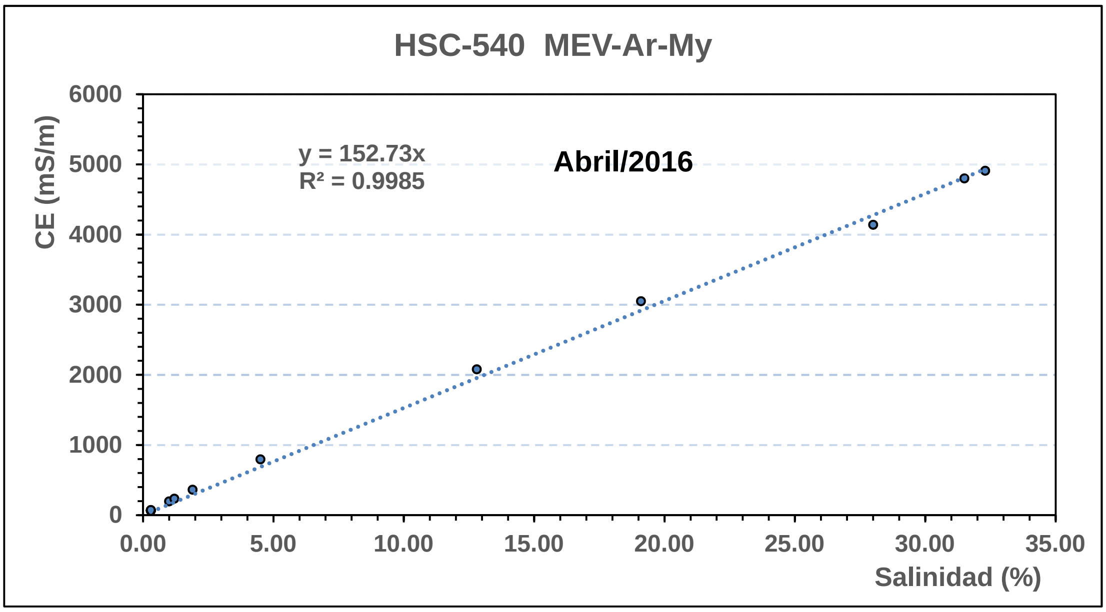

Figure 2-117: Relation between electrical conductivity (mS/m) and salinity (%), HSC-540

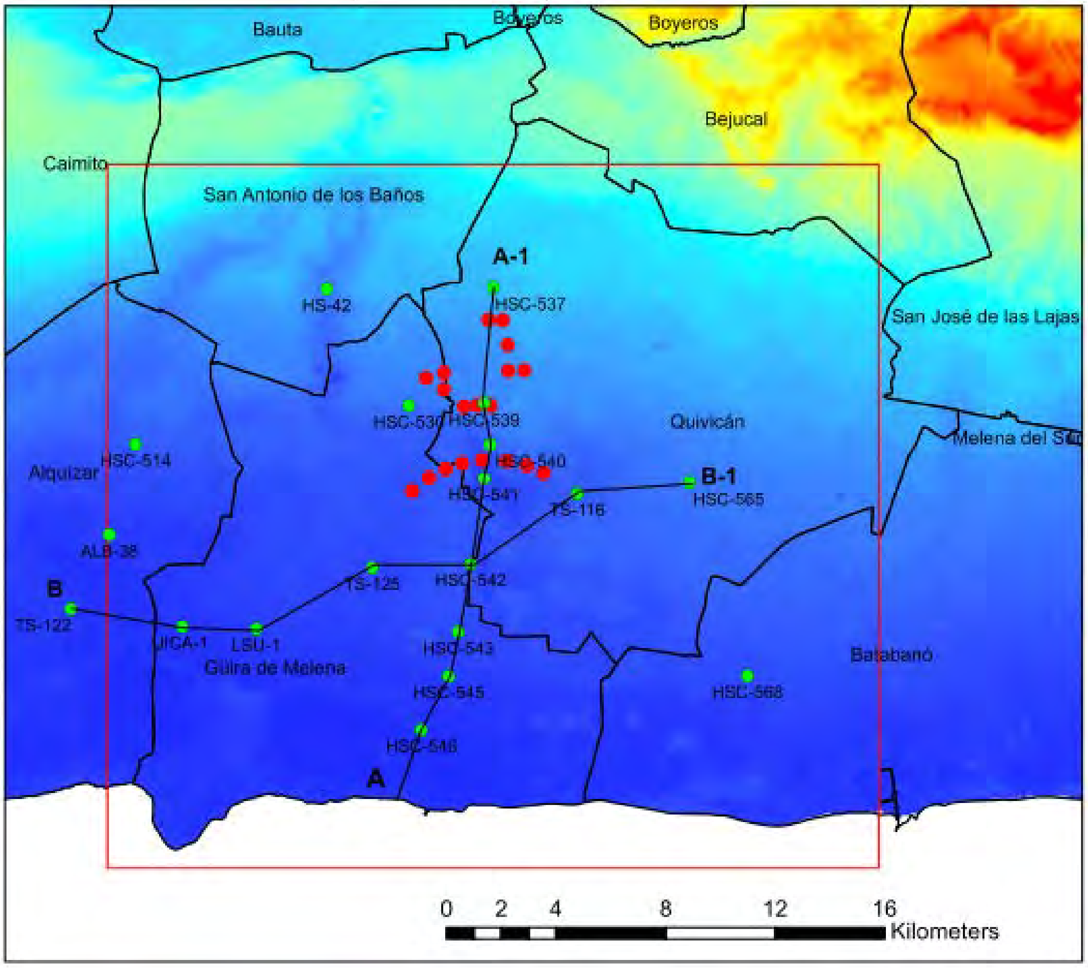

Figure 2-118: Section profile map

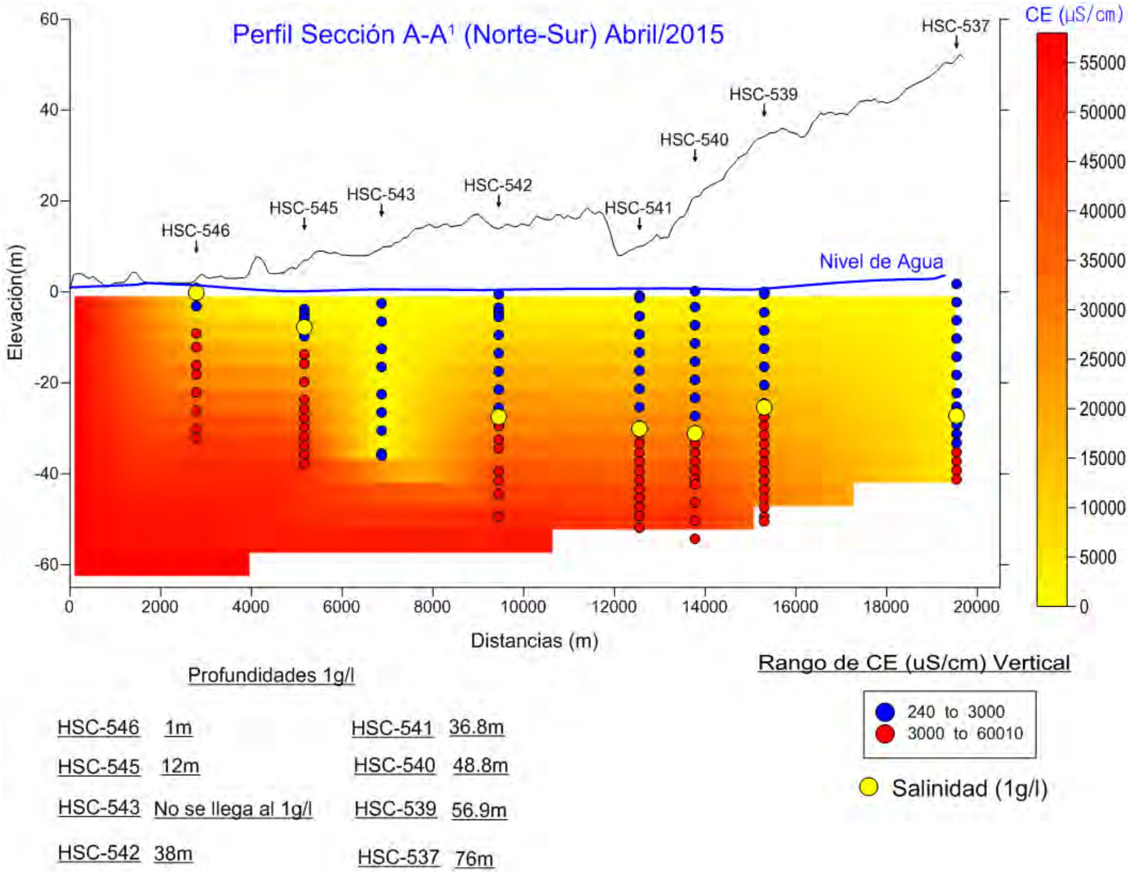

Figure 2-119: Profile of the section A-A[1] (north-south), April 2015

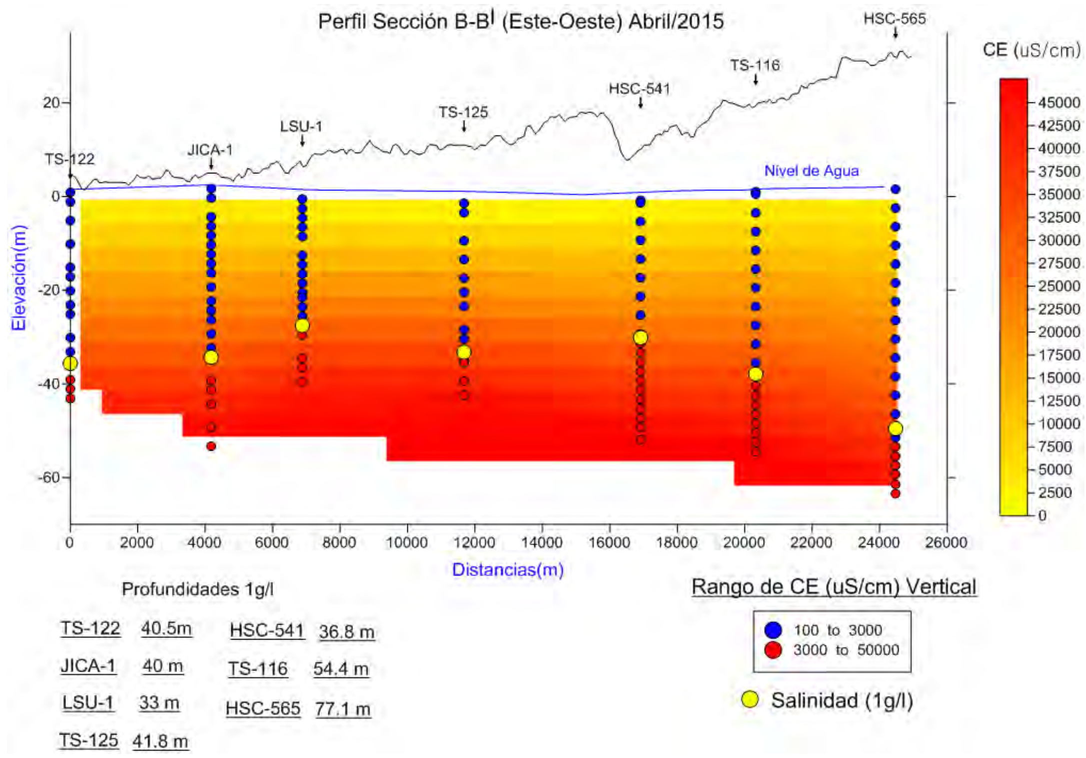

Figure 2-120: Profile of the section B-B[1] (east-west), April 2015

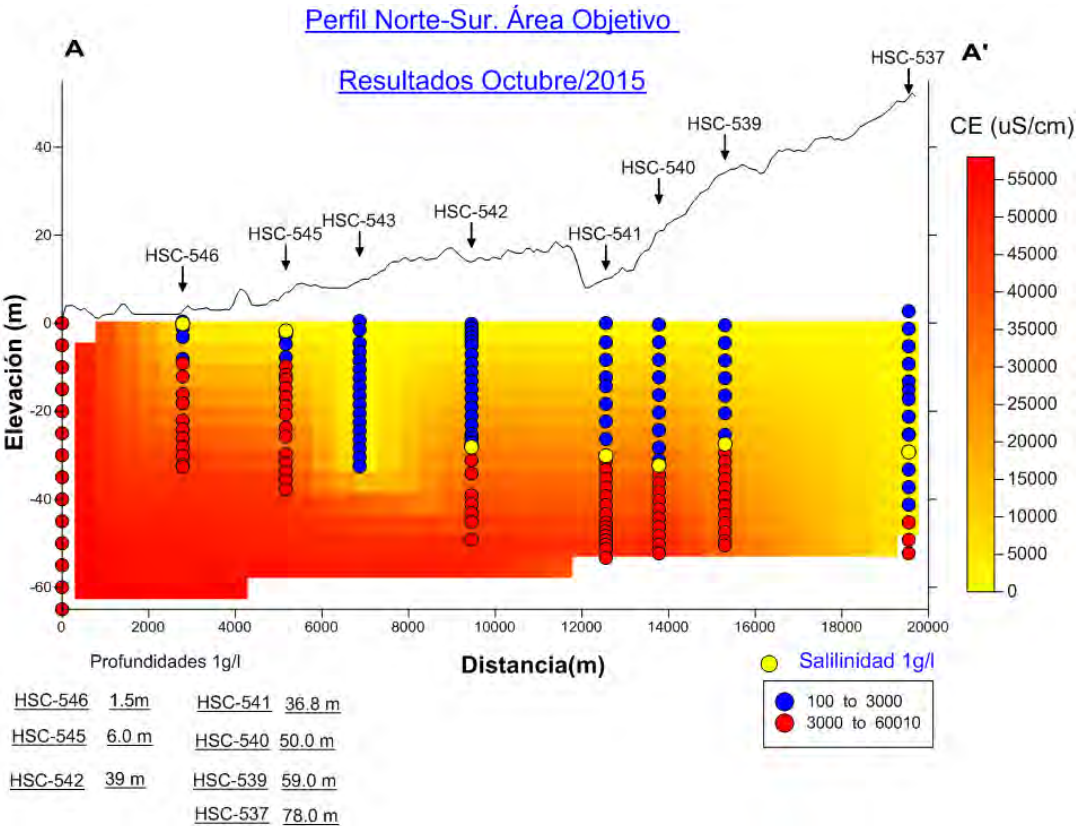

Figure 2-121: Profile of the section A-A[1] (north-south), October 2015

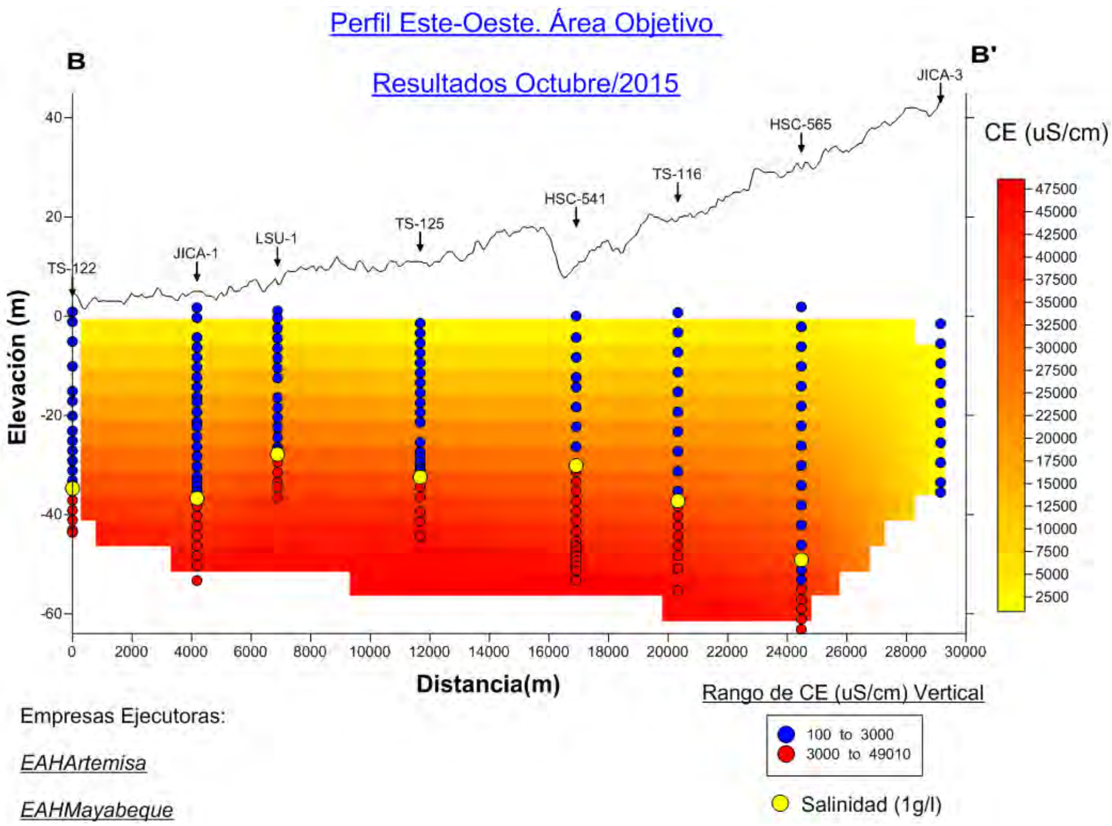

Figure 2-122: Profile of the section B-B[1] (east-west), October 2015

Table 2-40: Elevation 1g/l profile of the east-west (San Cristóbal-Alquízar)

Province	Initials	x	y	Elevation	EC_µS/cm	Salinity	Distance
Artemisa	PS-19.7	303300	315300	-15.42	2000	1	16730.4
Artemisa	ARB-9	308300	321150	-20.22	2140	1	24426
Artemisa	ARB-40B	328000	324700	-31.68	1980	1	44712.2
Artemisa	TS-122	336400	325100	-34.72	2720	1	53121.71

b.4 Problems related to other groundwater quality issues

In the analysis that has been carried out regarding groundwater quality in the aquifers and wells committed to the JICA Project, it has been found that one of the most important problems to be immediately taken into account are the levels of nitrite and nitrate in these waters, regardless of the fact that agriculture currently uses few nitrogen fertilizers.

Guideline values from the World Health Organization (WHO) and the Pan American Health Organization (PAHO) have placed these values, especially nitrates at maximum concentrations of 45 mgL-1 and there are many sources in this Habana-Matanzas plain, where are the provinces of Artemisa and Mayabeque are located with these affectations, which cause diseases mainly to children.

In addition, also in the surface waters that still flow through this plain there are high values of dissolved nitrate in the waters as a result of organic pollution that due to bacterial processes are transformed into nitrogenous compounds that are finally transformed into nitrites and nitrates.

As a result of all of the above, it is imperative that in addition to monitoring the aspects concerning seawater intrusion in our aquifers, there be also a monitoring of nitrite and nitrate concentrations in both, groundwater and surface waters, the latter caused by anthropogenic pollutions through organic matter.

b.5 Sources of pollution in the study area

A source of pollution is defined as the place where waste is produced. Depending on the nature of the waste, the sources can be domestic, municipal, industrial and agricultural. The first three, depending on the spatial nature of the pollution, are classified as point sources. On the other hand, the vast majority of agricultural and livestock activities (*of the extensive type*) fall into the category of diffuse sources, whose spatial field of action is more difficult to define as long as the production of waste occurs, not in a concentrated form, but along an entire front or area. Therefore, the Source of Pollution is where the waste is released, on the natural surface of the drainage basin (*either on the hillsides, sinkholes, or even on the own water surfaces*).

There are a total of 82 sources of pollution in the study area, classified according to the type of waste as shown in the following table:

Table 2-41: Focos contaminantes o fuentes localizadas de contaminación

Municipality	Drainage basin	Name of the source of pollution	x	y	Attached to	Type of waste
San Antonio de los Baños	San Antonio de los Baños	Aeropuerto San Antonio de los Baños	343359	337521	MITRANS	Industrial
San Antonio de los Baños	Río Ariguanabo	Asent. San Antonio de los Baños	345865	340793	OLPP	Municipal
San Antonio de los Baños	Río Ariguanabo	Hospital Iván Portuondo	344950	341500	MINSAP	Municipal
Guira de Melena	Vertiente Sur	Escuela (emerg.) Luz Caballero(Cuba-Etiopía)	347200	328700	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Ciro Berrios (viven evacuados)	346960	323400	OLPP	Domestic
Guira de Melena	Vertiente Sur	Escuela Comandancia de la Plata	347900	330700	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Cuba Jamaica	344800	326600	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Cuba Socialista	341600	337300	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Deportes Prov. Batalla de Ayacucho	349200	334400	INDER	Domestic
Guira de Melena	Vertiente Sur	Escuela Esp. de conducta Sithón Comandant	349600	334760	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Inst de Arte 13 de Marzo	343200	335900	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela interna Héroes de Bolivia	346808	328950	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Internacional de Cine y TV	343900	341500	CE	Domestic
Guira de Melena	Vertiente Sur	Escuela IPA Kin II Sung	342280	326360	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Juan Pablo Duarte	339740	325000	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Mártires de Humbolt 7	349900	343400	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Máximo Gómez Guira	350428	327000	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Mayia Rodríguez	342100	332100	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Niños Héroes de Chapultepec	346700	333300	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Provincial de Arte Eduardo Avela	344340	341345	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Rep. Cooperativa de Guyana	343500	323640	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	Escuela Rep. Popular de Angola	347850	336000	MINED	Domestic
Guira de Melena	Vertiente Sur	Escuela Victoria del Uvero	343000	334700	MINED	Domestic
San Antonio de los Baños	Río Ariguanabo	IPUEC Batalla del Jigüe	344600	341600	MINED	Domestic
Guira de Melena	Vertiente Sur	Cochiquera militar Mederos (UAM) Nuevo	345760	331104	MINFAR	Agricultural and livestock
Guira de Melena	Vertiente Sur	Porcino Camilo Ciénfuegos	347850	322600	MINAG	Agricultural and livestock
San Antonio de los Baños	Río Ariguanabo	Hotel Las Yagrumas	347000	341500	MINTUR	Domestic
Guira de Melena	Vertiente Sur	Cochiquera Aduana	345932	331278	MININT	Agricultural and livestock
San Antonio de los Baños	Río Ariguanabo	Cochiquera Las Cuevas	346083	341065	MINFAR	Agricultural and livestock
San Antonio de los Baños	Río Ariguanabo	Matadero de Aves San Antonio	347400	344100	MINAG	Municipal
San Antonio de los Baños	Ariguanabo	GE Cayo La Rosa	345645	340648	MINEM	Industrial
Guira de Melena	Vertiente Sur	GMI Los Moros (Güira)	343330	326610	MINFAR	Agricultural and livestock
Guira de Melena	Vertiente Sur	GMI Sonrrisa d/l Vict (Güira)	345550	327860	MINFAR	Agricultural and livestock
San Antonio de los Baños	Ariguanabo	CUBALUM (ensamb. Carpintería en Aluminio)	339788	341402	MINDUS	Industrial
San Antonio de	Ariguanabo	Parque Fluvial La Quintica, presa	345608	341402	OLPP	Municipal

los Baños		Muñíz				
Batabanó	Vertiente Sur	Asent. Batabanó	366770	321485	OLPP	Municipal
Bejucal	Ariguanabo	Asent. Bejucal	357665	344940	OLPP	Municipal
Quivicán	Quivicán	Asent. Quivicán	360732	333296	OLPP	Municipal
Bejucal	Quivicán	Asent. Edificios Médicos Quivicán	360570	334095	OLPP	Domestic
Quivicán	Vertiente Sur	Asent. La Salud	354460	339315	OLPP	Domestic
Quivicán	Vertiente Sur	Asent. Manuel Fajardo	351406	333912	OLPP	Domestic
Quivicán	Vertiente Sur	Asent. Pablo Noriega	357500	329200	OLPP	Domestic
Quivicán	Quivicán	Asent. San Felipe	365338	332840	OLPP	Domestic
Quivicán	Quivicán	Asent. Santa Mónica	358880	336620	OLPP	Domestic
Batabanó	Vertiente Sur	Asent. Surgidero de Batabanó	367089	318018	OLPP	Domestic
Quivicán	Quivicán	Grupo Electróg. Acdto. El Gabriel	351749	332503	INRH	Industrial
Quivicán	Vertiente Sur	Grupo Electrógeno Mangela	359831	335994	MINEM	Industrial
Batabanó	Vertiente Sur	Grupo Electrógeno Batabanó	366827	321227	MINEM	Industrial
Bejucal	Ariguanabo	Grupo Eléctrogeno Bejucal	355134	346397	MINEM	Industrial
Quivicán	ninguna	I. P. A. Fructuoso Rodríguez	359580	332880	MINED	Domestic
Quivicán	ninguna	Fábrica de Conservas 19 de Abril	359070	334440	MINAGRI	Industrial
Quivicán	ninguna	UEB Manuel Fajardo	351374	334228	AZCUBA	Industrial
Quivicán	ninguna	Fábrica de Conservas Caribe	357385	330710	MINAL	Industrial
Quivicán	ninguna	(IPUEC) Bernardo O`Higuins	359230	334220	MINED	Domestic
Quivicán	ninguna	(IPUEC) Cuba Canadá	357620	336700	MINED	Domestic
Quivicán	ninguna	(IPUEC) Gaspar García Galló	356600	337790	MINED	Domestic
Quivicán	ninguna	(IPUEC) XX Aniversario	356900	334710	MINED	Domestic
Quivicán	ninguna	Porcino Los Baez	355870	331420	MINAGRI	Agricultural and livestock
Quivicán	ninguna	Bioprocesos Cuba 10	351700	333700	AZCUBA	Industrial
Quivicán	ninguna	UEB Celulosa y Papel Cuba 9	357600	328900	AZCUBA	Industrial
Quivicán	ninguna	Porcino Finca Caparrosa	353015	330890	BIOCUBA FARMA	Agricultural and livestock
Quivicán	ninguna	Grupo electrógeno El Gabriel	351850	332195	MINEN	Industrial
Quivicán	Quivicán	Prisión Quivicán	364880	338430	MININT	Domestic
Quivicán	ninguna	Grupo Electrógeno Mangela	359831	335994	MINEM	Industrial
Quivicán	ninguna	Asentamiento humano Quivicán Edificios, Zona desarrollo Médicos	360570	334095	INRH	Domestic
Batabanó	ninguna	Porcino Inocencio	361500	326160	MINAGRI	Agricultural and livestock
Batabanó	Quivicán	Empresa Industrial Pesquera Batabanó	366615	318040	INRH	Industrial
Batabanó	C/Sin nombre	(IPUEC) IV Congreso	363590	325560	MINED	Domestic
Batabanó	C/Sin nombre	Fábrica de Conservas Batabanó	367090	321245	MINAL	Industrial
Batabanó	Quivicán	Escuela José Martí (Sta Rita)	365950	325000	MINED	Agricultural and livestock
Batabanó	ninguna	(IPUEC) Martires de la Coubre	368980	330000	MINED	Domestic
Batabanó	Quivicán	Porcino Hermanos Peňa	364700	326100	MINAGRI	Agricultural and livestock
Batabanó	ninguna	Porcino Camacho	358756	325068	MINAGRI	Agricultural and livestock
Batabanó	ninguna	Grupo Electrógeno Batabanó	366827	321227	MINEM	Industrial
Batabanó	Quivicán	Asentamiento humano Batabanó	367350	321460	INRH	Domestic
Batabanó	Quivicán	Asentamiento humano Surgidero de Batabanó	367089	318018	INRH	Domestic
Bejucal	Ariguanabo	Porcino de Comercio Bejucal	357500	345000	MINCIN	Agricultural and livestock
Bejucal	Ariguanabo	Matadero "El Terry"	356130	343550	MINAGRI	Agricultural and livestock
Bejucal	Ariguanabo	BioCen	357500	345500	BIOCUBA FARMA	Domestic/Biological

Bejucal	Ariguanabo	Grupo Eléctrogeno Bejucal	355134	346397	MINEM	Industrial
Bejucal	Ariguanabo	Asentamiento humano Bejucal	356900	345100	INRH	Municipal

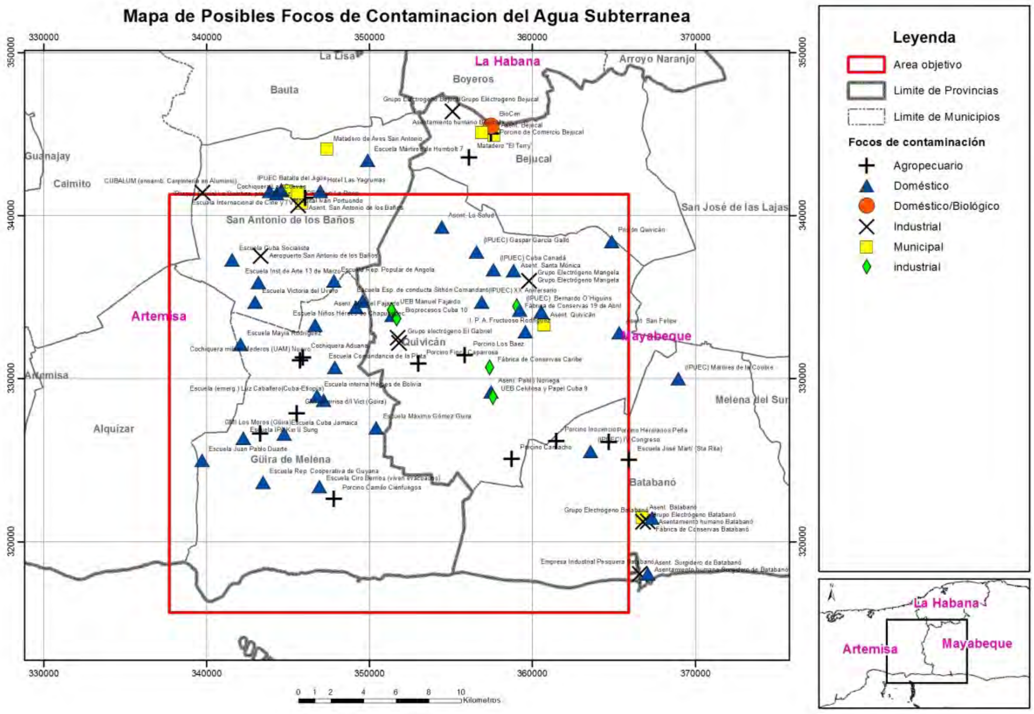

Figure 2-123: Map of the sources of pollution

c. Measures that have been taken in the past and their effects

In the 1970s, there was a need to carry out certain actions (cessation of pumping from saline wells, hydraulic protection works, etc.) which allowed to improve the seawater intrusion situation. Due to this, the construction of Dique Sur was planned at that time, and later (in the 1980s), the Pedroso-Mampostón-Güira channel was designed with the purpose of transferring large volumes of water to this basin and thus improving the situation of the intensive pumping of wells and, therefore, the salinization of the aquifer.

The subsurface water resource has been intensively exploited in the basin for decades as the only source of supply to the population, the industry and for irrigation. Due to this, there was an urgent need to find alternatives to solve the water-deficit problems, and, on the other hand, to attenuate the process of seawater intrusion, already evident and aggravated during the 1980s. Thus, the construction of significant hydraulic works, such as the Dique Sur and the Pedroso - Güira master channel were explained, for the water decanting channel between basins.

The closure of canals and ditches draining the aquifer to the sea and the experimental partial construction of a 4.1 km stretch of clay dike parallel to the coast were also ordered to raise the water level in the swampy area and make the groundwater circulate beneath the peat that freely escaped to the sea through the aforementioned channels.

At the boundary of the coastal area, the Dique Sur was built, with a length of 50 km and an elevation of 1.0 to 1.5 m and 32 spillways, with an elevation of 0.70 and 0.90 m cross it in all its extension. The main purpose of the work is to retain part of the groundwater discharged through the channels by runoff into the Gulf of Batabanó, restoring the flow lines below the wetland. Its purpose is to create a barrier against the seawater surface intrusion, to increase surface water levels in the swamp, to increase groundwater resources, to improve the groundwater quality by washing the coastal strip and to limit the seawater intrusion into the aquifer by increasing the underground circulation of freshwaters to the sea.

From 1989 onwards, the pumping tests on the spillways of Dique Sur started, and a volume of 103 x 10^6 m^3 / was discharged through them according to the observation data of 1990. As there are not enough measurements either before or after the construction of the dam, it is not possible to determine with an adequate precision the magnitude of the transformation of the surface flow into underground flow.

There are divergent opinions regarding the effectiveness of Dique Sur and its possibilities for improving hydrogeological conditions. Conversely, some researchers believe that it has caused an ecological change in the area. However, it is necessary to point out that the ecological balance was broken from the very moment when the drainage channels of the swampy area were built, which, currently make the groundwater discharge possible in an immediate way. For this reason, from the hydrogeological point of view, it is not correct to facilitate the groundwater drainage in a superficial manner if it does not exist naturally.

Around the work, in the swampy area, a series of bores were previously constructed where measurements of vertical hydrochemistry and resistivity were systematically taken. According to the results obtained in a short period of time, an evident decrease of the total mineralization in some bores has been observed, reaching a variation from 35 g/L to less than 1 g/L, as for example in the DSC-7 and DSC-8 bores and in others up to 10 g/L, increasing the thickness of freshwater in that area.

c.1 Dique Sur

The construction of the Dique Sur in the years 1985-1990 had the following objectives:

- Restrict the runoff of surface water into the sea.
- Partially interrupt the underground flow.
- Create a quagmire of the coastal strip upstream of the dam.
- Prevent the sea penetration and the groundwater salinization.

Dique Sur Structure

This work consists of the construction of an embankment of low height (1 m of absolute height) that will reach a total length of 51.7 km parallel to about 500 m along the south coast (See Figure 2-124), from the Surgidero de Batabanó until after Majana beach, as well as some 40.7 km of access roads perpendicular to the dike. It also has some 40 works of factories, of which 32 are spillways.

This causes the rise of the water levels in the area until reaching an approximate spot height of 0.70 and 0.9 m that coincides with the spill spot height and in turn with NAN, having foreseen a depth in the spillways of 0.20 m. That is to say, NAM will be 0.90 and 1.10 m. In the cases in which extraordinary rainfall occurs, it will not exceed much more of the 1.00 m spot height, as the water would surpass the embankment and this would work as a huge spillway that will be cut off by the water itself in several points.

The water level rise throughout the swamp area will have the effect of a hydraulic barrier against the seawater penetration, displacing these both, horizontally and vertically, allowing to diminish the groundwater slopes above this area, thus reducing the water flow to the sea and achieving a greater water retention in the basin in general. These combined displacements are the most important ones because the increase of freshwater reserves depends on them.

Table 2-42: Technical parameters of Dique Sur and its sections

Parámetros	U/M	Tramo IV	Tramo I	Tramo II	Tramo V	Tramo III	Total
Nombre del tramo		Batabanó-Cardoso	Cardoso-Cajío	Cajío-Majana	Majana-Guanimar	Guanimar-Punta Cayamas	
Longitud del tramo	m	12.800	3.950	9.450	14.672	10.807	51.679
Longitud del acceso	m		1.727	5.700	10.500	9.077	27.004
Cantidad de aliviaderos	u	7	2	6	10	7	32
Tipo de aliviaderos	-	umbral ancho	umbral ancho	umbral ancho	umbral ancho	umbral ancho	
Capacidad de evacuación	m^3/s	19,6	5,74	21,16	42,58	32,41	121,49
Nivel de aguas normales (N.A.N.)	msnm	0,7	0,7	0,7	0,9	0,9	0,7 - 0,9
Nivel de aguas máxima (N.A.M.)	msnm	0,9	0,9	0,9	1,2	1,2	0,9 - 1,2
Ancho de la corona	m	7	7	7	7	7	7
Cota de corona	m	1	1	1	1,5	1,5	1 - 1,5
Tipo de dique	-	Homogéneo de arcilla	Homogéneo de arcilla	Homogéneo de arcilla	Homogéneo de arcilla	Homogéneo de arcilla	
Volumen para (N.A.N.)	hm^3	5,6	0,26	6,6	8,8	4,0	25,26

It has been possible to determine that the influence of the rise of the levels in the swampy area has been reflected to distant points to 16 km from the coast, where the groundwater levels do not exceed 2 m, as well as a decrease of the salt content of the surface waters and groundwater, from 4 g/L to slightly more than 1 g/L. Although in points like the Cajío Aqueduct the decrease of the salinity is evident even for its users.

These beneficial effects of this investment have repercussions in the field of wells of the aqueduct supplying Havana with a reduction of the depressive cone with the increase of the supply from the South.

In the years after the closure of the channels, no affected plantations of casuarina have been observed in the swampy areas, at least at first sight, although the rise of the water levels affects the chopping and extraction of timber.

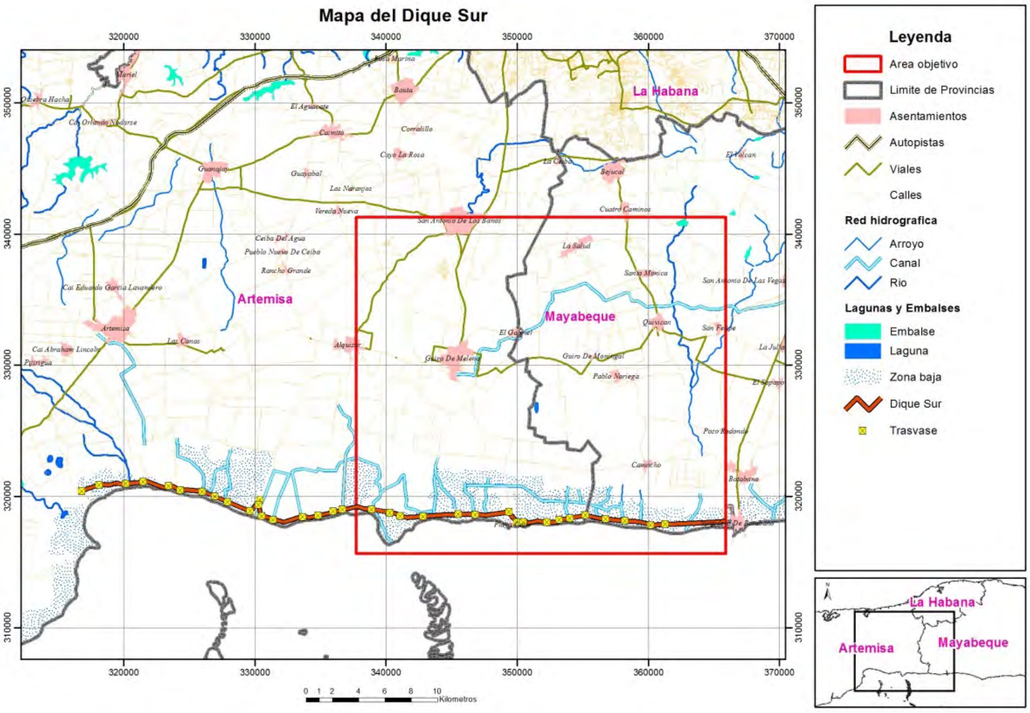

Figure 2-124: General map of Dique Sur

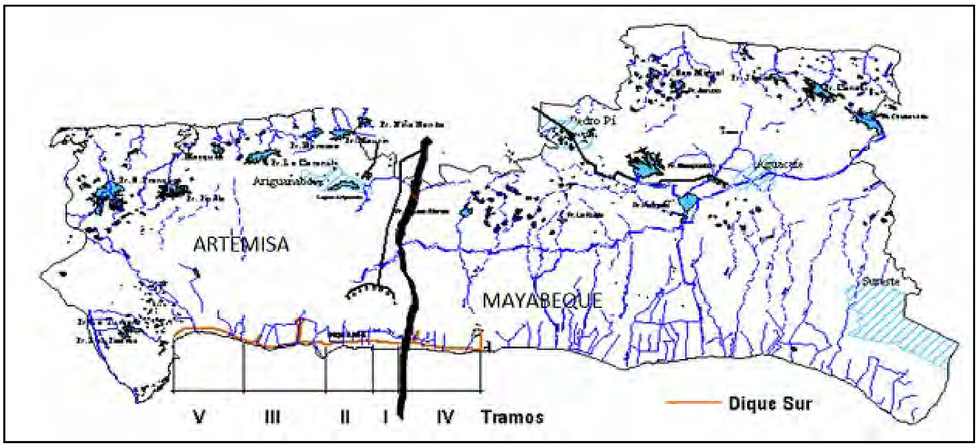

Figure 2-125: Sections of Dique Sur, provinces of Artemisa and Mayabeque.

d. Results of the "Water Balance" of GEARH regarding groundwater management

The Water Balance, a process leaded and directed by GEARH through the INRH's system, is the main tool to materialize the integrated water management in Cuba, in order to meet the needs of the economy, the society and the protection of the environment. The Water Balance as a planning tool through which efficiency is measured in the state and private intake, regarding the availability of the resource, is a process of conciliating the interests of all branches of the economy and the society in order to access the different water sources to which they are linked.

It is a process of demands, analysis of the availabilities and the technical state of the supplying sources, discussion, justification and allocation of water volumes to meet the set needs, without violating the exploitation conditions and restrictions of the sources. These availabilities depend on the rainfall behavior. For example, for the year 2016, the Water Balance allocated 305.00 Hm^3 of all the exploitable resource of the underground basin, which is of 375.00 Hm^3, and there is no deficit in terms of the water demanded by the clients for different activities such as: agricultural irrigation, human consumption and other uses.

The operating losses were also balanced both, those caused by the conduction in the master channels, and the losses in the aqueduct systems which are estimated values of the water table recharge. The following graph shows the compliance with the Water Balance at the end of the 1st quarter.

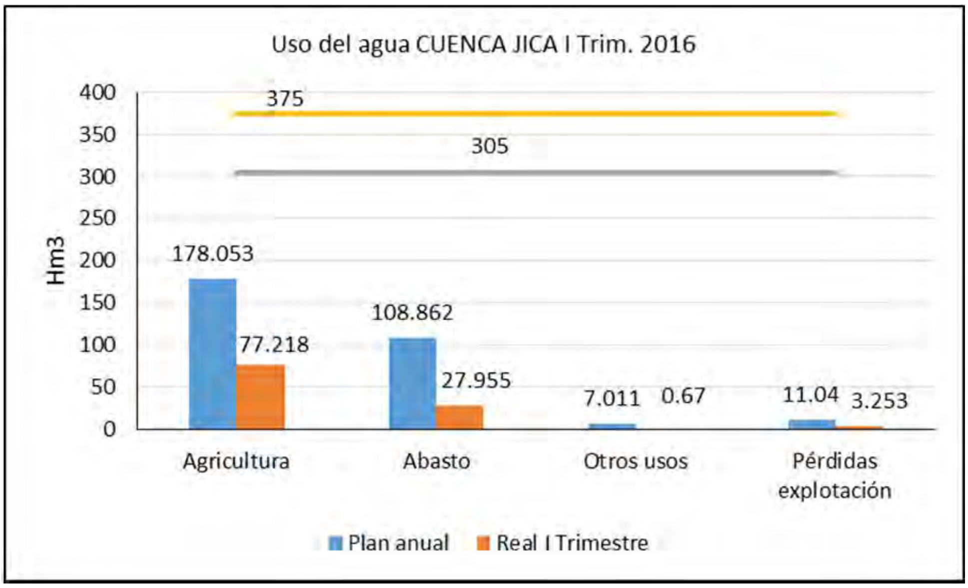

Figure 2-126: Water use JICA BASIN 1st quarter 2016

For the specific conditions of the drought seasons that cyclically affect the country, a thorough work is required that allows to begin a recovery process of stabilizing the deliveries of the supply sources from a more rational water distribution with the minimum possible affectations.

As a result of this, it has been possible to maintain the sustainability of the resource in the study area; that has been maintained as investments have not been considerable.

Water Balance Book 2016 Artemisa (Table 1. Summary by water organizations assigned by the Balance)

RESUMEN DE LA PROPUESTA DE BALANCE

BALANCE DE AGUA Año: 2016

GRUPO EMPRESARIAL DE APROVECHAMIENTO DE LOS RECURSOS HIDRÁULICOS

CUENCA JICA

Tabla #1 UM: hm³

Página: 1

Impreso: 25/05/16

ORG/RAMA/ACT/EMP	FUENTE	TEC.	NIVEL	NORMA		DEMANDA					NIVEL	ASIGNACIÓN					DÉFICIT				
		RGO.	ACTIV	N.	B.	TOTAL	I-III	IV-VI	VII-IX	X-XII	ACTIV	TOTAL	I-III	IV-VI	VII-IX	X-XII	TOTAL	I-III	IV-VI	VII-IX	X-XII
Total						125.228	36.424	29.139	24.763	34.902		125.228	36.424	29.139	24.763	34.902	0.000	0.000	0.000	0.000	0.000
MINISTERIO DE LA AGRICULTURA						107.519	31.186	24.965	20.993	30.375		107.519	31.186	24.965	20.993	30.375	0.000	0.000	0.000	0.000	0.000
AGRICULTURA NO CAÑERA			11170.97			106.766	30.960	24.787	20.825	30.194	11170.975	106.766	30.960	24.787	20.825	30.194	0.000	0.000	0.000	0.000	0.000
ARROZ PRIMAVERA			42.575			0.544	0.136	0.134	0.138	0.136	42.575	0.544	0.136	0.134	0.138	0.136	0.000	0.000	0.000	0.000	0.000
CCS Frank Pais (Güira)	HS-3	G	1.643	8944.000	12777.000	0.021	0.005	0.006	0.005	0.005	1.643	0.021	0.005	0.006	0.005	0.005	0.000	0.000	0.000	0.000	0.000
CPA Amistad Cuba Paises Nórdicos	HS-3	G	8.844	8944.000	12777.000	0.113	0.028	0.027	0.030	0.028	8.844	0.113	0.028	0.027	0.030	0.028	0.000	0.000	0.000	0.000	0.000
Emp Agrop Cultivos Varios (Güira)	HS-3	G	14.557	8944.000	12777.000	0.186	0.047	0.045	0.047	0.047	14.557	0.186	0.047	0.045	0.047	0.047	0.000	0.000	0.000	0.000	0.000
UBPC Heroes Yaguajay (Güira)	HS-3	G	17.531	8944.000	12777.000	0.224	0.056	0.056	0.056	0.056	17.531	0.224	0.056	0.056	0.056	0.056	0.000	0.000	0.000	0.000	0.000
CÍTRICOS Y FRUTALES			455.520			3.594	0.982	0.812	0.653	1.147	455.520	3.594	0.982	0.812	0.653	1.147	0.000	0.000	0.000	0.000	0.000
CCS 1ro de Mayo (Güira)	HS-3	G	5.700	4400.000	8800.000	0.050	0.012	0.012	0.013	0.013	5.700	0.050	0.012	0.012	0.013	0.013	0.000	0.000	0.000	0.000	0.000
CCS Abel Santa Maria (Alq)	HS-3	G	4.140	4400.000	8800.000	0.036	0.011	0.008	0.005	0.012	4.140	0.036	0.011	0.008	0.005	0.012	0.000	0.000	0.000	0.000	0.000
CCS Alvaro Reinoso (Alq)	HS-3	G	9.000	4400.000	8800.000	0.079	0.024	0.018	0.012	0.025	9.000	0.079	0.024	0.018	0.012	0.025	0.000	0.000	0.000	0.000	0.000
CCS Antero Regalado (Güira)	HS-3	G	4.400	4400.000	8800.000	0.039	0.009	0.010	0.010	0.010	4.400	0.039	0.009	0.010	0.010	0.010	0.000	0.000	0.000	0.000	0.000
CCS Camilo Cienfuegos (Alq)	HS-3	A	3.200	4400.000	5500.000	0.018	0.004	0.005	0.004	0.005	3.200	0.018	0.004	0.005	0.004	0.005	0.000	0.000	0.000	0.000	0.000
CCS Camilo Cienfuegos (Guira)	HS-3	G	19.700	4400.000	8800.000	0.173	0.043	0.043	0.044	0.043	19.700	0.173	0.043	0.043	0.044	0.043	0.000	0.000	0.000	0.000	0.000
CCS Frank Pais (Alq)	HS-3	G	45.200	4400.000	8800.000	0.399	0.120	0.092	0.060	0.127	45.200	0.399	0.120	0.092	0.060	0.127	0.000	0.000	0.000	0.000	0.000
CCS Frank Pais (Güira)	HS-3	G	14.800	4400.000	8800.000	0.130	0.032	0.032	0.033	0.033	14.800	0.130	0.032	0.032	0.033	0.033	0.000	0.000	0.000	0.000	0.000
CCS José A Echeverria (Alq)	HS-3	G	20.300	4400.000	8800.000	0.179	0.029	0.000	0.000	0.150	20.300	0.179	0.029	0.000	0.000	0.150	0.000	0.000	0.000	0.000	0.000
CCS Niceto Pérez (Güira)	HS-3	G	4.600	4400.000	8800.000	0.040	0.010	0.010	0.010	0.010	4.600	0.040	0.010	0.010	0.010	0.010	0.000	0.000	0.000	0.000	0.000
CCS Pedro R.Santana (Alq)	HS-3	G	20.100	4400.000	8800.000	0.178	0.053	0.041	0.027	0.057	20.100	0.178	0.053	0.041	0.027	0.057	0.000	0.000	0.000	0.000	0.000
CCS Raúl Cepero Bonilla (Güira)	HS-3	G	3.700	4400.000	8800.000	0.033	0.008	0.008	0.009	0.008	3.700	0.033	0.008	0.008	0.009	0.008	0.000	0.000	0.000	0.000	0.000
CCS Rubén Mtnez Villena (Alq)	HS-3	G	112.300	4400.000	8800.000	0.987	0.296	0.227	0.148	0.316	112.300	0.987	0.296	0.227	0.148	0.316	0.000	0.000	0.000	0.000	0.000

Water Balance Book 2016 Mayabeque (Table 1. Summary by water organizations assigned by the Balance)

RESUMEN DE LA PROPUESTA DE BALANCE

BALANCE DE AGUA Año: 2016

GRUPO EMPRESARIAL DE APROVECHAMIENTO DE LOS RECURSOS HIDRÁULICOS

CUENCA JICA

Tabla #1 UM: hm³

Página: 1

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ORG/RAMA/ACT/EMP	FUENTE	TEC.	NIVEL	NORMA		DEMANDA					NIVEL	ASIGNACIÓN					DÉFICIT				
		RGO.	ACTIV	N.	B.	TOTAL	I-III	IV-VI	VII-IX	X-XII	ACTIV	TOTAL	I-III	IV-VI	VII-IX	X-XII	TOTAL	I-III	IV-VI	VII-IX	X-XII
Total						86.220	27.475	21.070	13.583	24.092		86.220	27.475	21.070	13.583	24.092	0.000	0.000	0.000	0.000	0.000
MINISTERIO DE LA AGRICULTURA						55.884	17.447	13.063	8.936	16.438		55.884	17.447	13.063	8.936	16.438	0.000	0.000	0.000	0.000	0.000
AGRICULTURA NO CAÑERA			6492.980			52.923	16.706	12.324	8.206	15.687	6492.980	52.923	16.706	12.324	8.206	15.687	0.000	0.000	0.000	0.000	0.000
ARROZ PRIMAVERA			5.000			0.064	0.000	0.064	0.000	0.000	5.000	0.064	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UBPC Ruben Marichal (Bat)	HS-4	G	5.000	8936.000	12766.000	0.064	0.000	0.064	0.000	0.000	5.000	0.064	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CÍTRICOS Y FRUTALES			113.660			1.015	0.258	0.256	0.239	0.262	113.660	1.015	0.258	0.256	0.239	0.262	0.000	0.000	0.000	0.000	0.000
CCS 2da Declaración (Quivican)	HS-3	G	5.100	4400.000	8800.000	0.045	0.011	0.011	0.011	0.012	5.100	0.045	0.011	0.011	0.011	0.012	0.000	0.000	0.000	0.000	0.000
CCS Antonio Guiteras (Quiv)	HS-3	G	1.800	4400.000	8800.000	0.016	0.004	0.004	0.004	0.004	1.800	0.016	0.004	0.004	0.004	0.004	0.000	0.000	0.000	0.000	0.000
CCS Camilo Cienfuegos (Quiv)	HS-3	G	1.100	4400.000	8800.000	0.024	0.006	0.006	0.006	0.006	1.100	0.024	0.006	0.006	0.006	0.006	0.000	0.000	0.000	0.000	0.000
CCS Cuba Socialisa (Quivican)	HS-3	G	3.500	4400.000	8800.000	0.031	0.008	0.007	0.007	0.009	3.500	0.031	0.008	0.007	0.007	0.009	0.000	0.000	0.000	0.000	0.000
CCS Eduardo Garcia (Quiv)	HS-3	G	3.600	4400.000	8800.000	0.032	0.008	0.008	0.008	0.008	3.600	0.032	0.008	0.008	0.008	0.008	0.000	0.000	0.000	0.000	0.000
CCS José A. Echeverria (Quiv)	HS-3	G	4.300	4400.000	8800.000	0.038	0.010	0.010	0.009	0.009	4.300	0.038	0.010	0.010	0.009	0.009	0.000	0.000	0.000	0.000	0.000
CCS José Luis Tasende (Quiv)	HS-3	G	15.000	4400.000	8800.000	0.132	0.033	0.033	0.033	0.033	15.000	0.132	0.033	0.033	0.033	0.033	0.000	0.000	0.000	0.000	0.000
CCS Juan M Marquez (Quivican)	HS-3	G	2.400	4400.000	8800.000	0.021	0.005	0.005	0.005	0.006	2.400	0.021	0.005	0.005	0.005	0.006	0.000	0.000	0.000	0.000	0.000
CCS Julio Trigo (Quiv)	HS-3	G	3.100	4400.000	8800.000	0.027	0.007	0.007	0.006	0.007	3.100	0.027	0.007	0.007	0.006	0.007	0.000	0.000	0.000	0.000	0.000
CCS Martires de Barbados (Quivican)	HS-3	G	18.110	4400.000	8800.000	0.159	0.040	0.039	0.039	0.041	18.110	0.159	0.040	0.039	0.039	0.041	0.000	0.000	0.000	0.000	0.000
CCS Nicomedes Corvo (Quiv)	HS-3	G	27.000	4400.000	8800.000	0.238	0.060	0.059	0.059	0.060	27.000	0.238	0.060	0.059	0.059	0.060	0.000	0.000	0.000	0.000	0.000
CCS Nicomedes Corvo (Quiv)	Sist. Mamp-Ped-G/Canal	G	5.000	4400.000	8800.000	0.044	0.015	0.014	0.000	0.015	5.000	0.044	0.015	0.014	0.000	0.015	0.000	0.000	0.000	0.000	0.000
CPA Pedro Rguez Santana (Quiv)	HS-3	G	2.700	4400.000	8800.000	0.024	0.006	0.006	0.006	0.006	2.700	0.024	0.006	0.006	0.006	0.006	0.000	0.000	0.000	0.000	0.000
Gja Avicola L P V (Quivican)	HS-3	A	0.300	4400.000	5500.000	0.002	0.000	0.001	0.000	0.001	0.300	0.002	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Gja Avicola La Soria (Quivican)	HS-3	G	0.300	4400.000	8800.000	0.003	0.000	0.001	0.001	0.001	0.300	0.003	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Gja Avicola San Agustin (Quivican)	HS-3	G	0.150	4400.000	8800.000	0.001	0.000	0.001	0.000	0.000	0.150	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000

3 CHANGES IN THE CIRCUMSTANCES SURROUNDING GROUNDWATER

3.1 Meteorology

The following graphs show the annual precipitation and the probability of precipitation (exceedence probability, non-exceedance probability) obtained by the Hazen method at the main rainfall observation points.

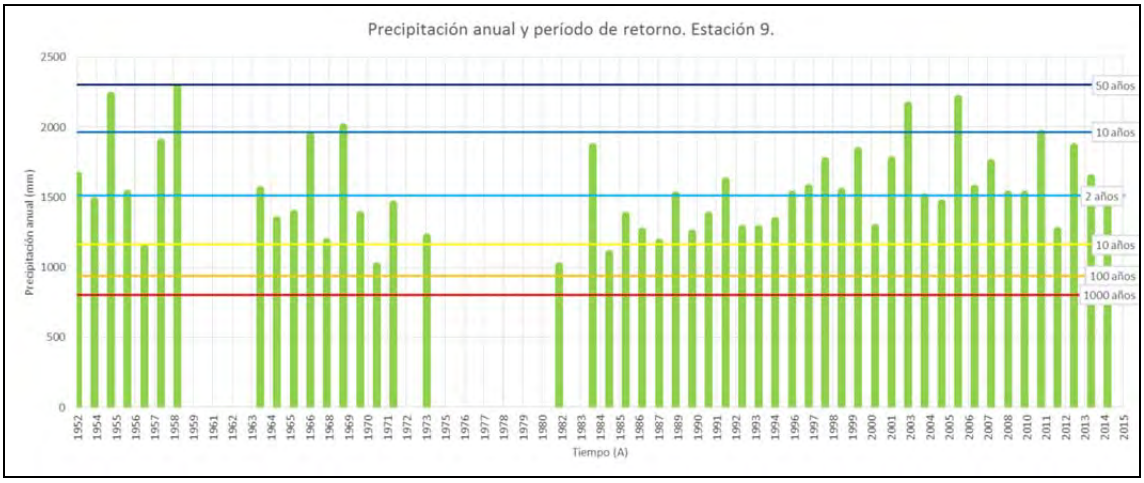

Figure 3-1: Station 9

Figure 3-2: Station 17

Figure 3-3: Station 18

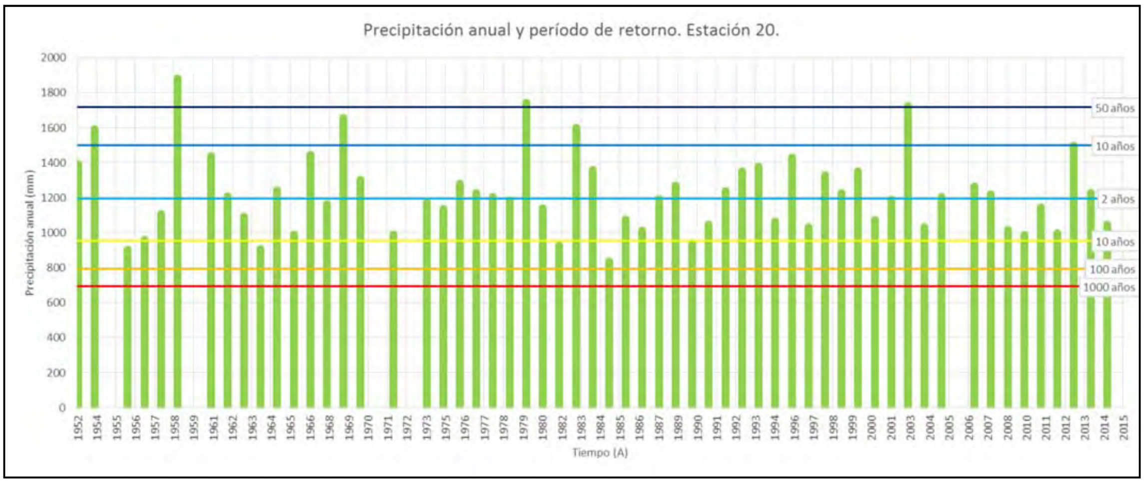

Figure 3-4: Station 20

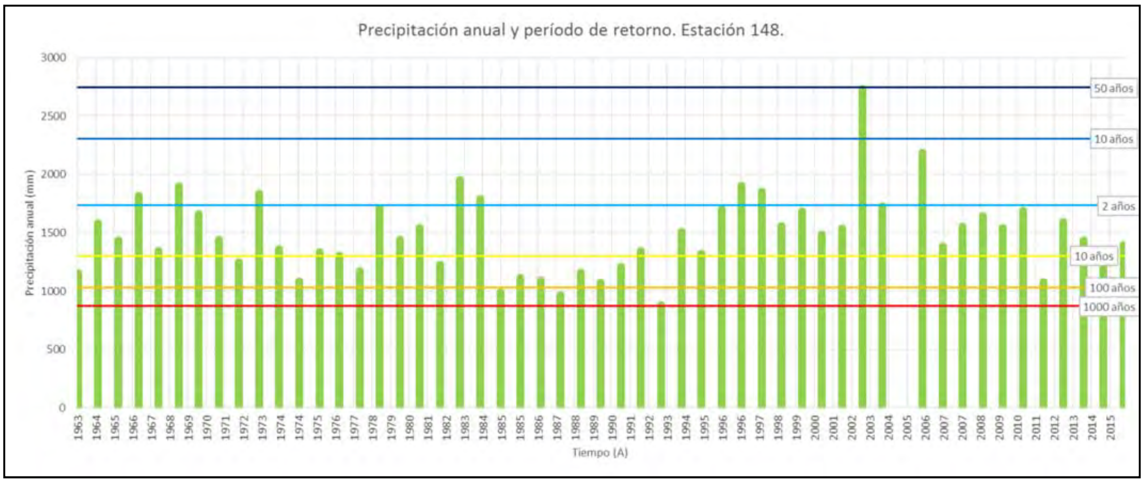

Figure 3-5: Station 148

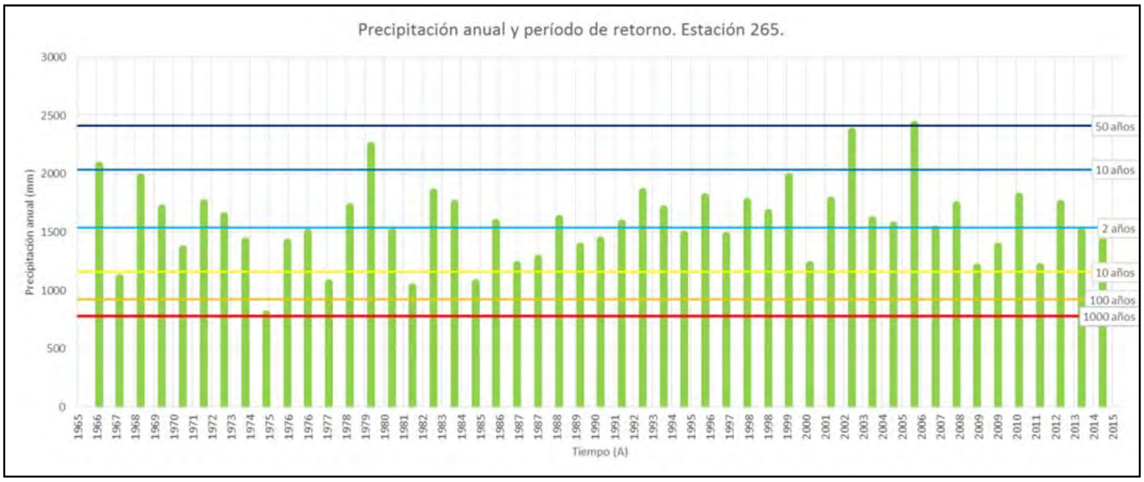

Figure 3-6: Station 265

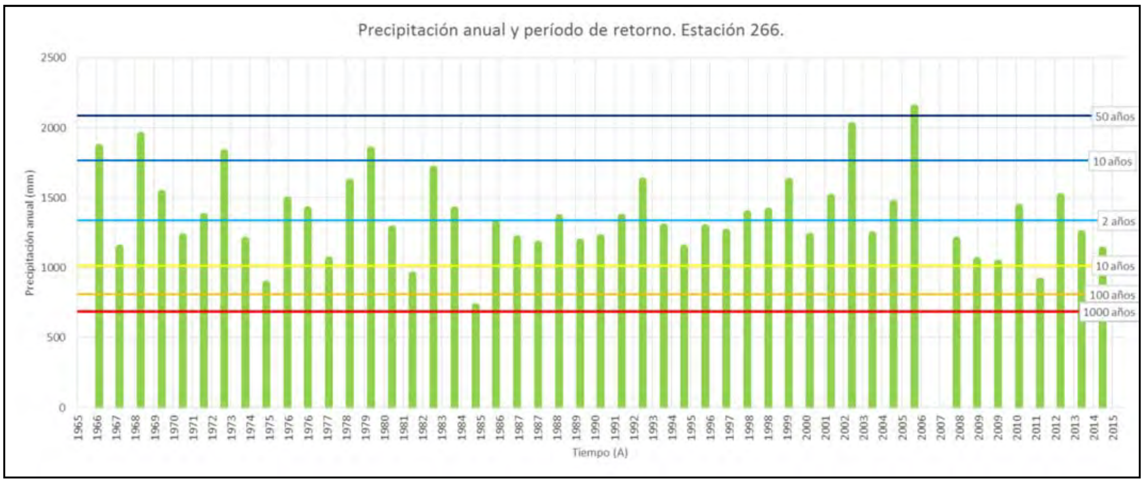

Figure 3-7: Station 266

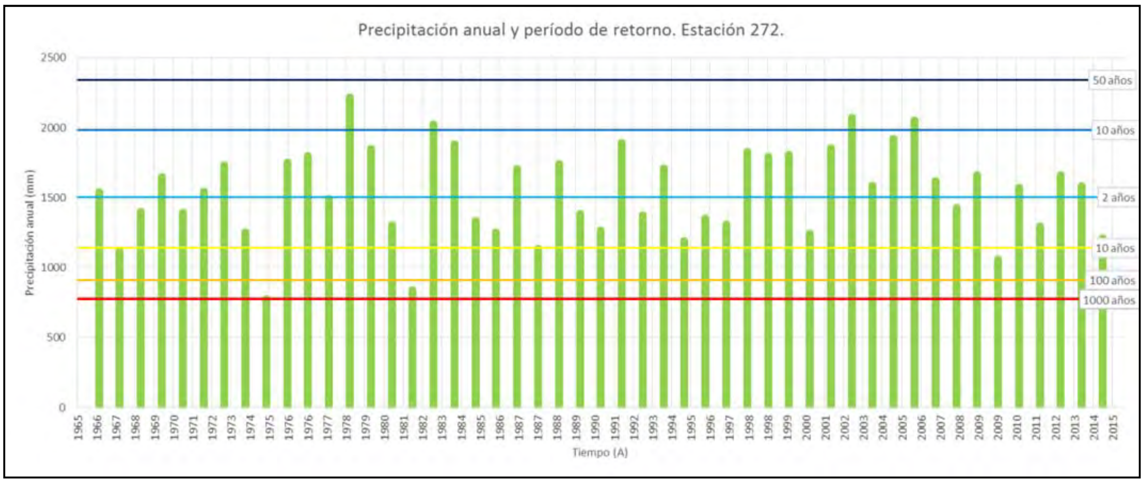

Figure 3-8: Station 272

3.2 Groundwater Recharge

In the long run, it is prospective that the amount of groundwater recharge decreases by urbanization.

There are no short-term land change plans that may affect groundwater recharge.

3.3 Saltwater and Surface Water

PROJECTIONS OF CHANGES IN THE MEAN SEA LEVEL

Determining the trend of the mean sea level rise and its extreme values for the present and the future is the most complex and current problem faced by humanity. Climate Change is not a man-made effect, but its accelerated development over a short period of time is. In the history of the planet, a larger or smaller number of changes similar to those currently taking place have occurred in all geologic eras. The NMM fluctuation level graph of the Quaternary shows the subsidence and uplift movements of this era.

The island countries, such as Cuba, are the most vulnerable to sea level change. Studies are being carried out in Cuba and measures are being taken to mitigate the effects of Climate Change and the rise of the sea. Also, multidisciplinary studies of the coastal strip and its influence on the mainland are carried out by CITMA as governing body with the participation of several organizations.

One of the main topics is to know what would be the flooding spot height that would occupy the new coastline, for which two calculation dates were taken, 2050 with a water level rise of 0.27 m and 2100 with 0.85 m as initial heights.

The entire coastline is monitored and the vulnerability of the coastline and its adaptation average is classified.

The entire southern border of the study area of the project is a coastal swamp stripe of low altitude where the marine regression for these two scenarios was predicted (Figure 3-9).

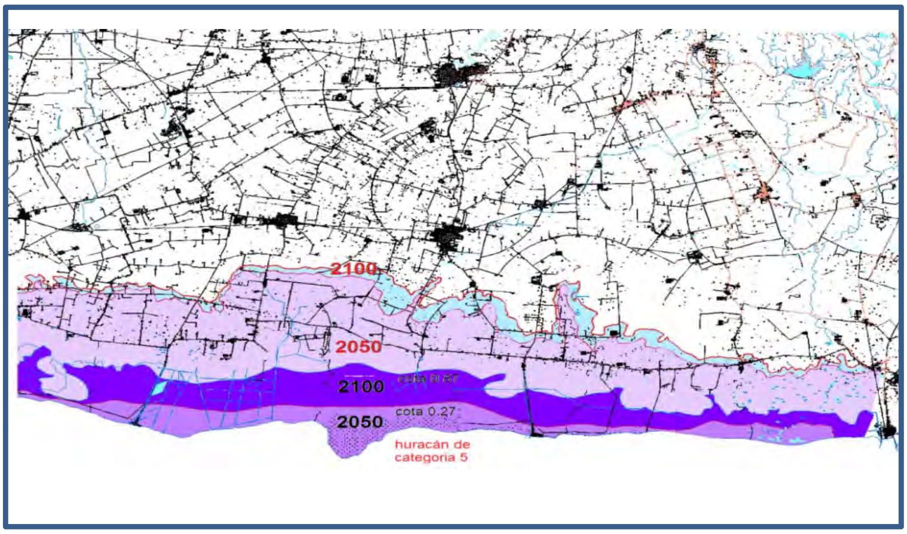

Figure 3-9: Swampy coastal stripe

Changes in sea level predicted for the years 2050 and 2100 are shown in lilac and purple, as well as the sea penetration as a result of major swells caused by a category five hurricane. (Enrique and Amaury, Macro-Project CC, 2008).

Studies with aerial and cosmic images from different years of the area showed that between 1956 and 1997 in an area close to the HS IV section and to the East of the town of Batabanó, the sea occupied 95 m inland displacing the coastline and changing the marine and terrestrial ecosystem.

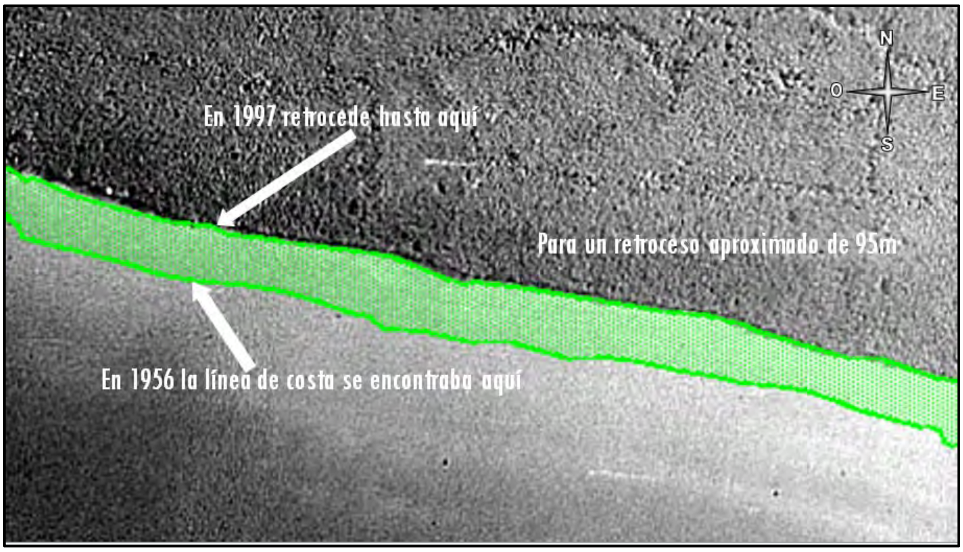

Figure 3-10: Coastline displacement from 1956 to 1997 in a coastal sector between Surgidero de Batabanó and Playa Mayabeque. (A. C. Hernández Zanuy, Institute of Oceanology from CITMA).

If these two scenarios were to occur, the surface drainage network would be activated in a land strip equivalent to the periodically flooded areas, with the activation of palaeovalleys (Figure 3-11), with the change of the regional baseline level. This rise of the sea level affects the aquifer with the displacement of the saltwater wedge and the groundwater level rise causing that emerged karstic forms be flooded and those occupying a low altimetric position serve as ways of discharge of the aquifer.

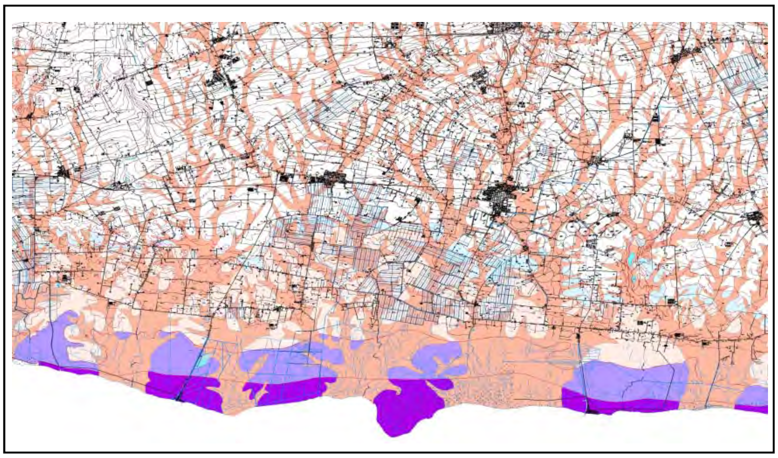

Figure 3-11: Map of the palaeovalley network and the prediction of the mean sea level rise in the project sector

3.4 Groundwater Use

The monthly quantity of groundwater intake for the past five years is shown in the following figure.

Although a simple comparison cannot be performed as there has been an improvement in the latest data precision, the amount of groundwater intake shows a downward trend. In particular, the quantity of groundwater intake of the dry season is decreasing drastically.

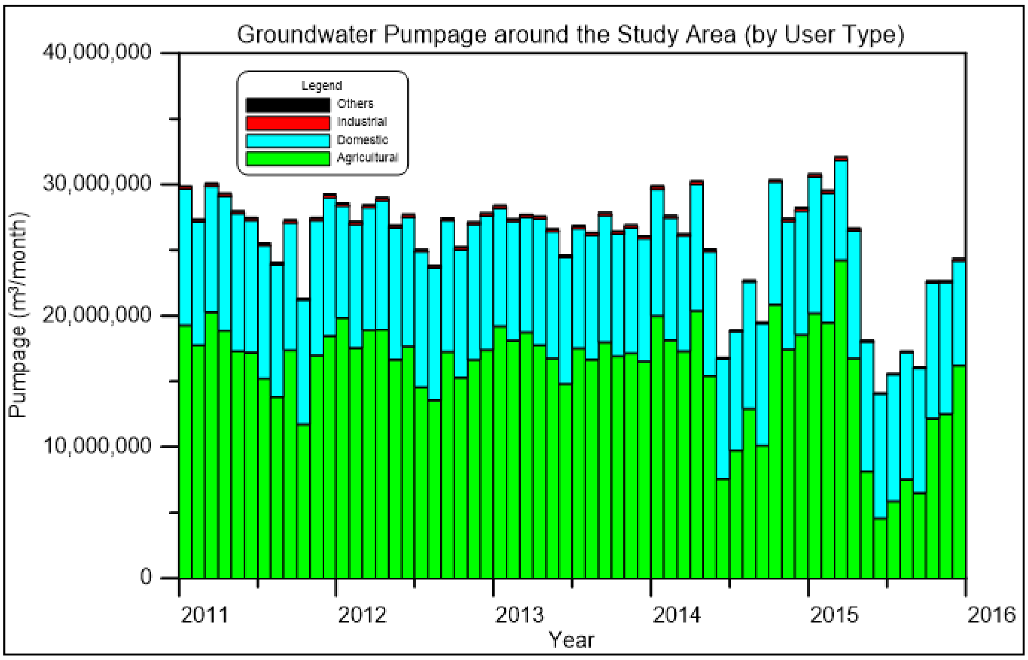

Figure 3-12: Estimation of the monthly quantity of groundwater intake (2011-2015)

4 GROUNDWATER CONSERVATION TARGET

4.1 Set of Conservation Objectives

- **Environmental conservation** is the different ways to protect and preserve the future of nature, or some of its parts: water resources, different species, ecosystems, landscape values, among others.
- The human species is destroying the last few remaining natural areas; it is extinguishing species of plants and animals; it is contaminating the sea, air, soil and water.
- Should this process continue, the human being is not only impoverishing his environment and himself, but he is endangering his own survival as a species.
- Overexploitation of groundwater is not as evident as that of lakes and rivers. There is less visual evidence and the effects of excessive extraction of groundwater take longer to be noticeable.
- In the last decades much more water has been extracted from underground sources than in the past, without taking into account the capacity of recharge of aquifers.
- Negative consequences such as reduction of water levels, pollution and depletion of resources, can be permanent or have a very long duration over time.

4.2 Target Value of Groundwater Level

a. Managed conservation criteria

The exploitable resources can be equal to or less than the hyperanual average recharge of the aquifer, that is to say, it is recommended to extract a volume of water that at the maximum is equal to what enters as average in many years, which would not alter the dynamic equilibrium condition of the aquifer.

$$Qe \leq \lambda\ Qn$$

b. Determination of target values for groundwater conservation

- As desired short-term value, the Very Unfavorable Level limit was chosen:

$$\text{NMD} = \text{N}_{\text{crítico}} + \frac{\Delta h}{2}\ \text{(recarga neta media)}$$

- As the final target value, the Unfavorable Level limit was chosen:

$$\text{NMD} = \text{N}_{\text{crítico}} + \Delta h\ \text{(recarga neta media)}$$

c. Preservation target values (groundwater level)

Below two groundwater levels established by the method mentioned above.

Table 4-1: Target conservation values (Groundwater level)

Hydrodynamic basin	Code	Name	Wished value Short term (mamsl)	Final target value (mamsl)
HS-3	HSC-523	Rancherita	0.47	0.92
HS-3	pozo HSC-541	Bufón	0.27	0.54
HS-3	HSC-543	Segui	1.01	1.30
HS-3	HSC-563	19 de Abril	7.04	8.15
HS-3	LSU-1	El Junco	0.83	1.11
HS-3	LSU-3	La Salud	13.07	13.97
HS-3	A-19A	La Sonora	3.40	4.55
HS-4	HSC-586	Apeadero	4.03	4.85
HS-3	LSU-8	Camacho	0.40	0.00
HS-3	HSC-516	Pequeña Cabaña	13.50	14.05
HS-3	HSC-542	Sotolongo	0.67	0.97
HS-3	HSC-530	Amaros	0.33	0.70
HS-3	TS-125	Liliana Dimítrova	0.70	1.17
HS-3	HSC-512	Delicias	0.99	1.29
HS-3	HS-42	Monte Ramos	5.52	6.75
HS-3	HSC-547	Porraspita	0.28	0.62
HS-3	HSC-549	Árbol del Pan	0.55	0.88
HS-3	HSC-534	La Cuchara	3.08	3.40

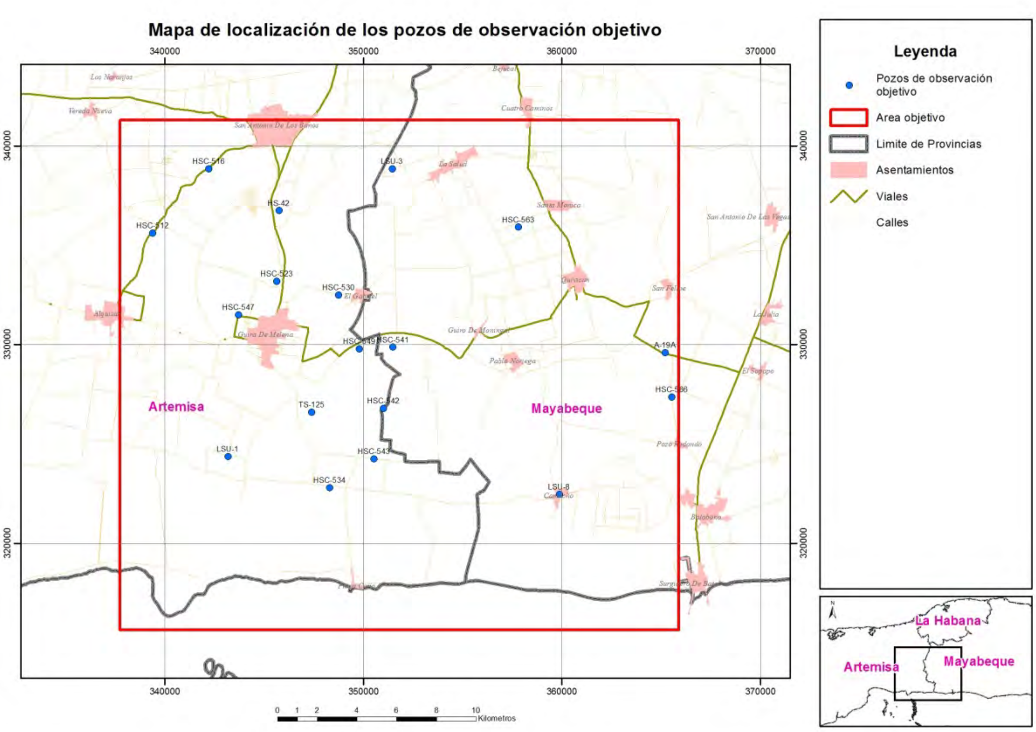

Figure 4-1: Location map of target observation wells (Groundwater level)

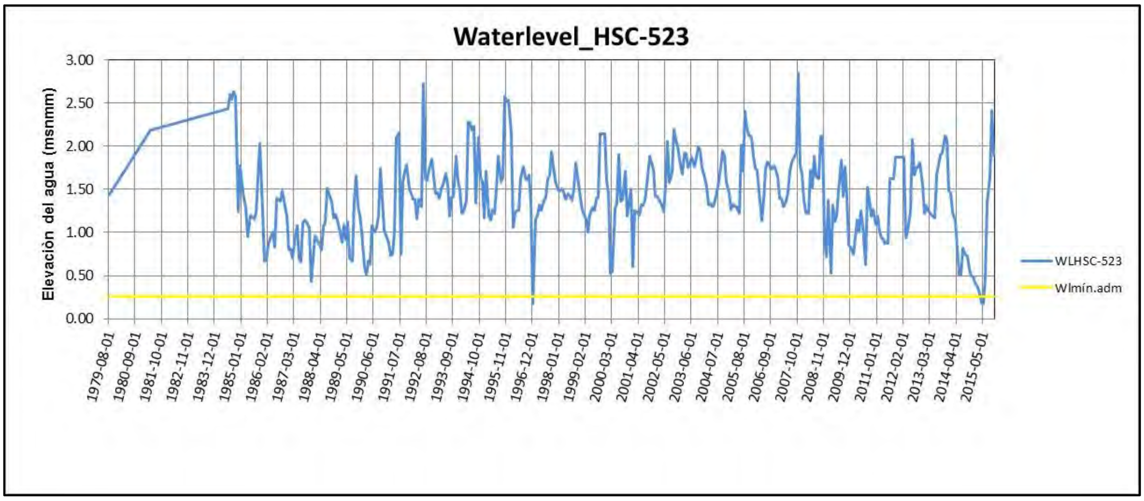

Figure 4-2: HSC-523

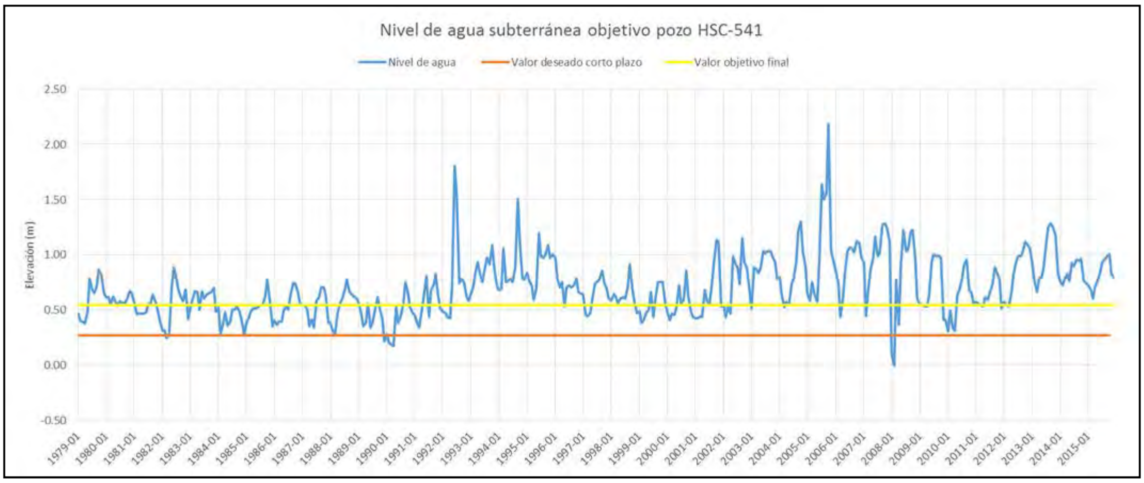

Figure 4-3: HSC-541

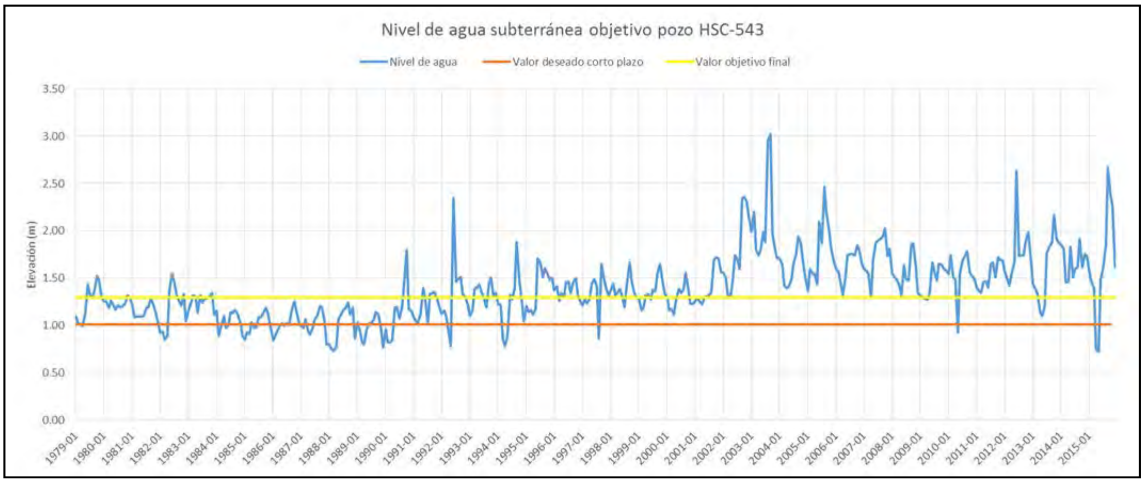

Figure 4-4: HSC-543

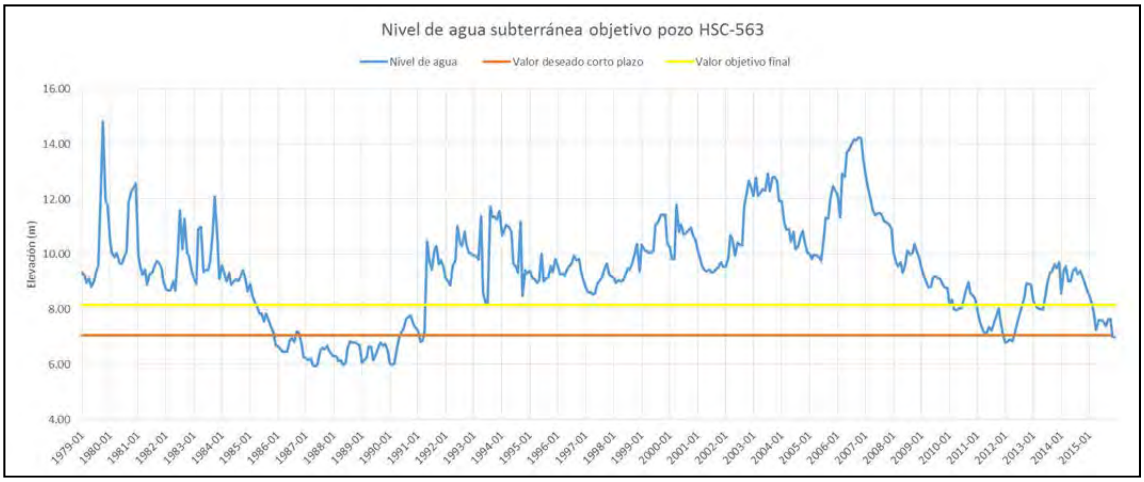

Figure 4-5: HSC-563

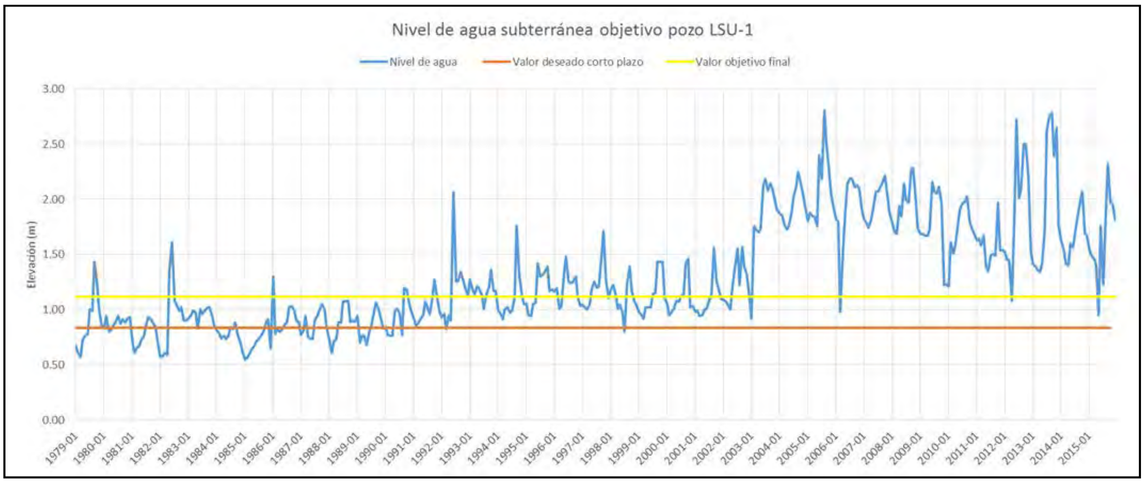

Figure 4-6: LSU-1

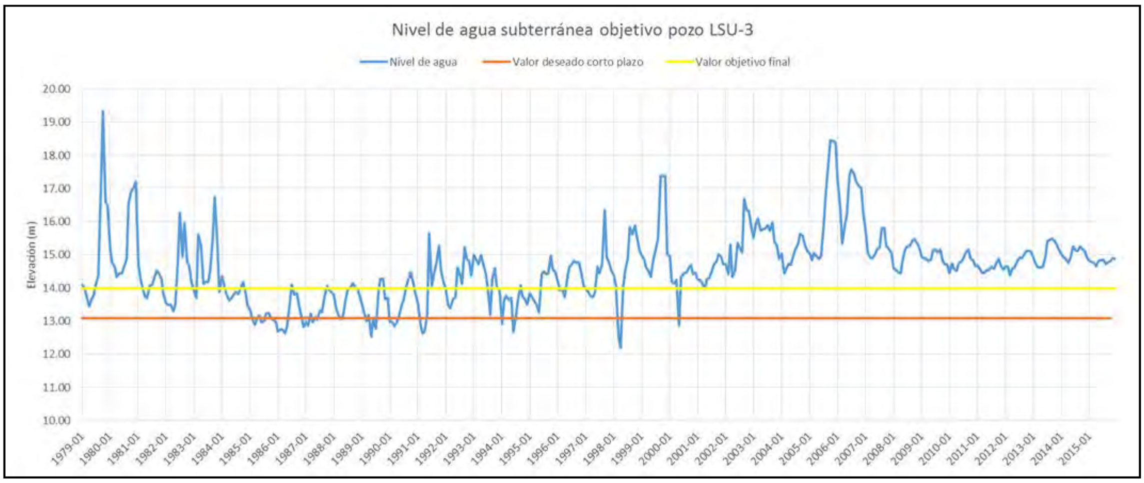

Figure 4-7: LSU-3

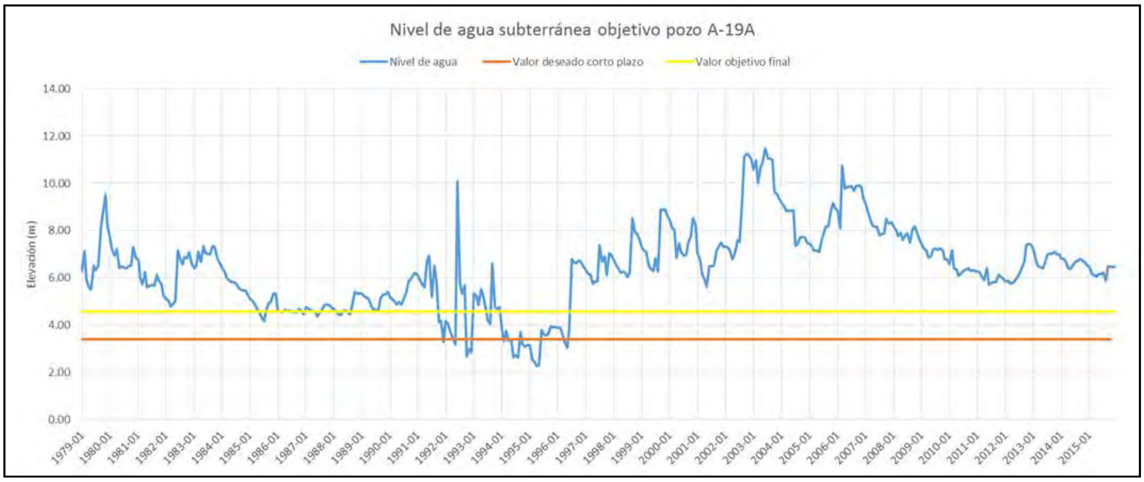

Figure 4-8: A-19A

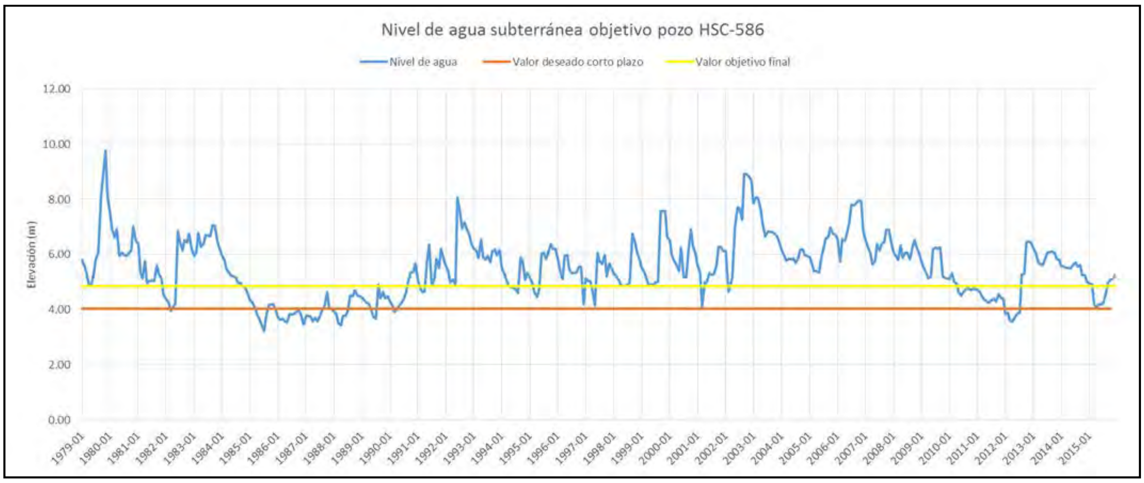

Figure 4-9: HSC-586

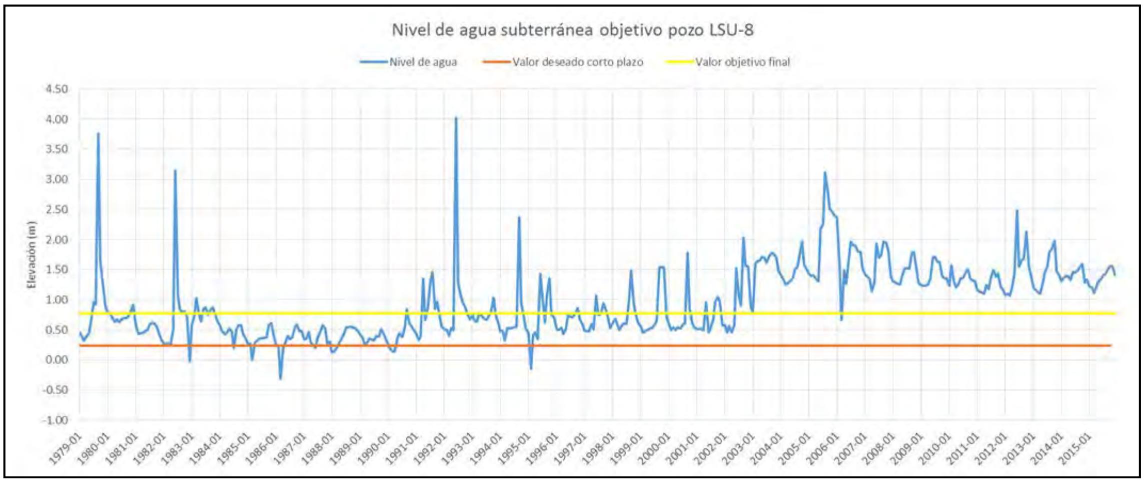

Figure 4-10: LSU-8

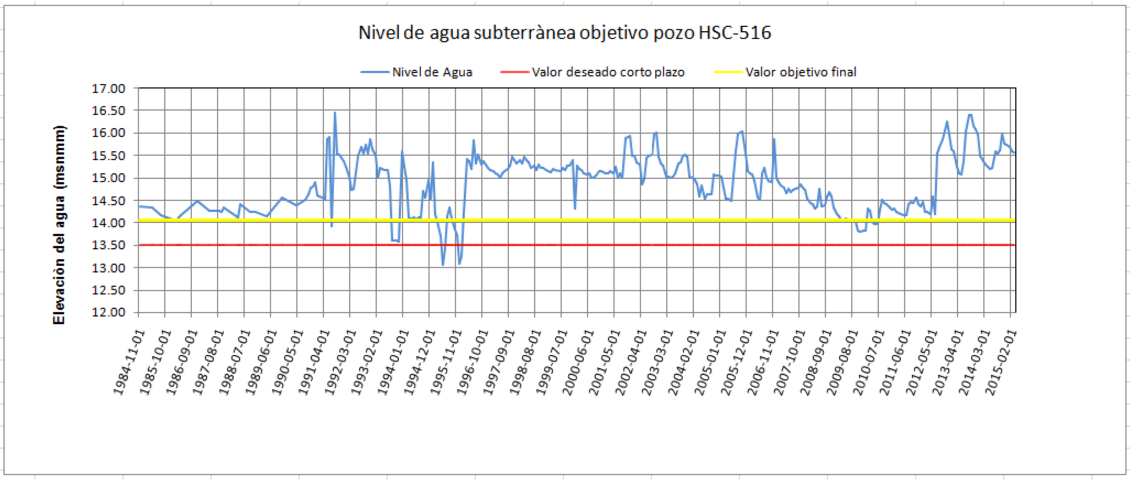

Figure 4-11: HSC-516

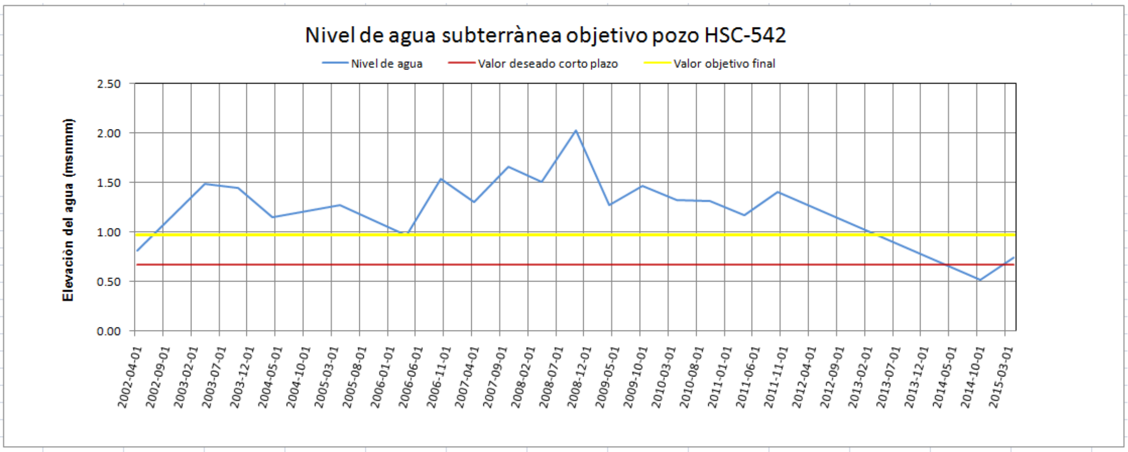

Figure 4-12: HSC-542

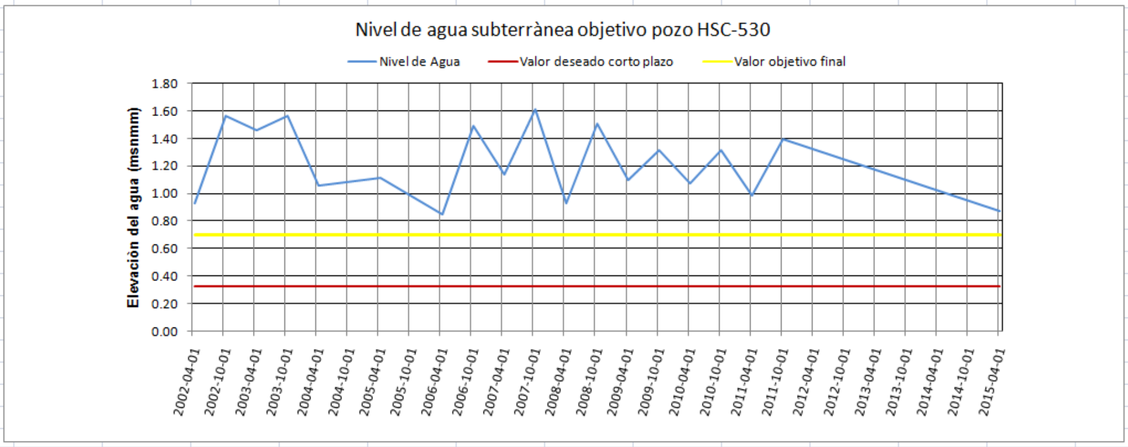

Figure 4-13: HSC-530

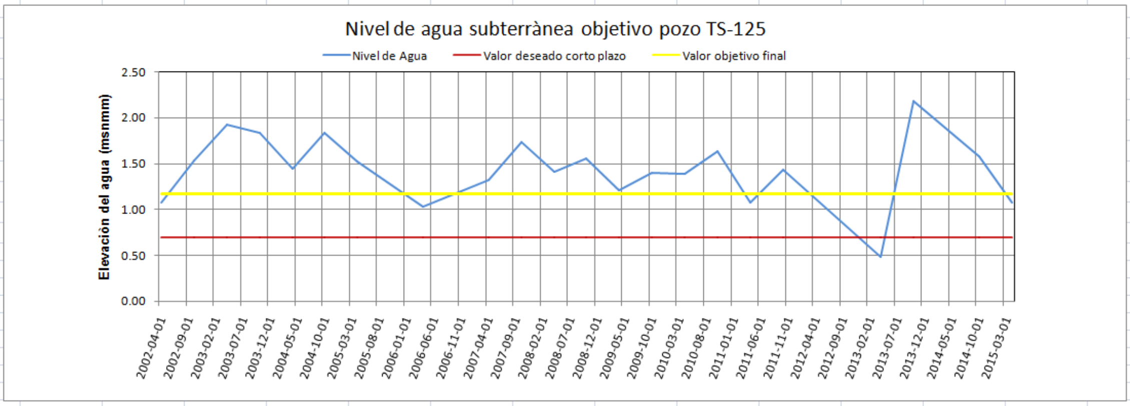

Figure 4-14: TS-125

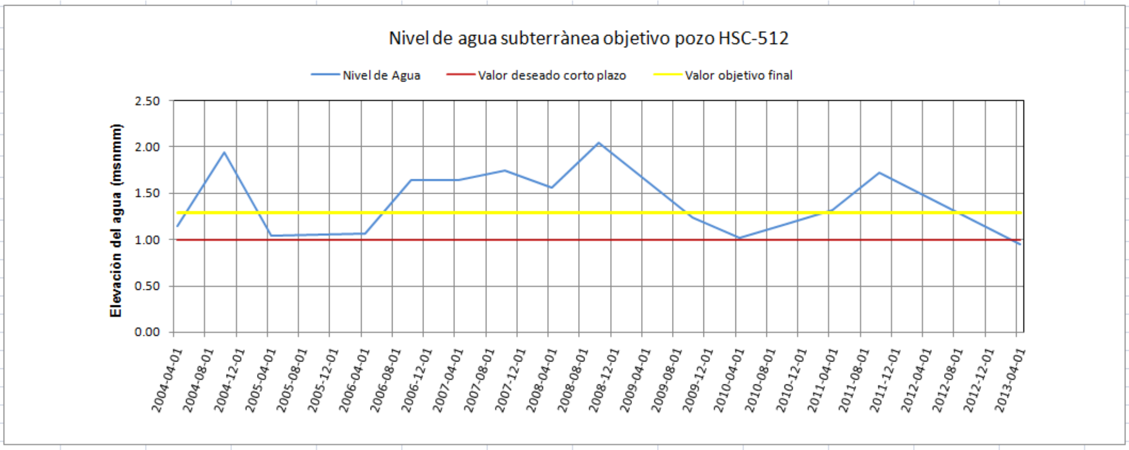

Figure 4-15: HSC-512

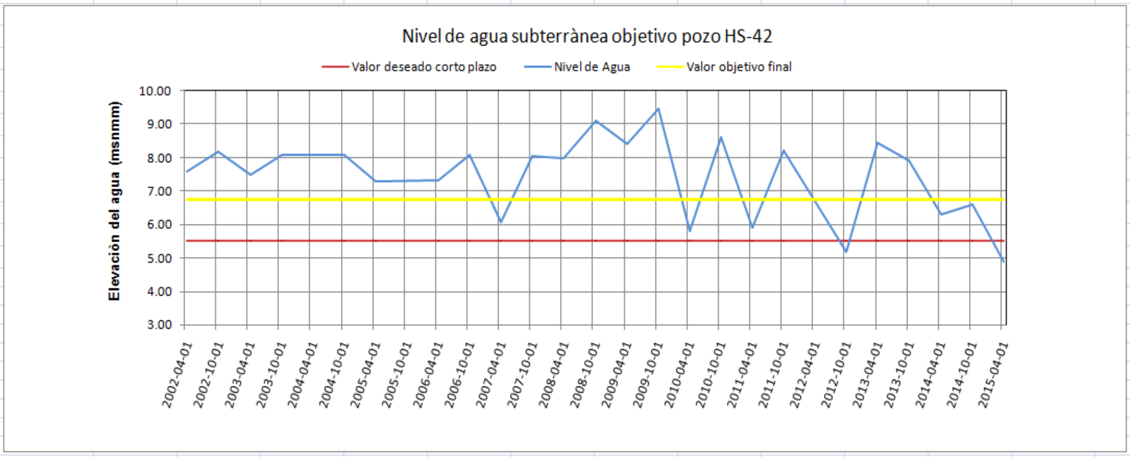

Figure 4-16: HS-42

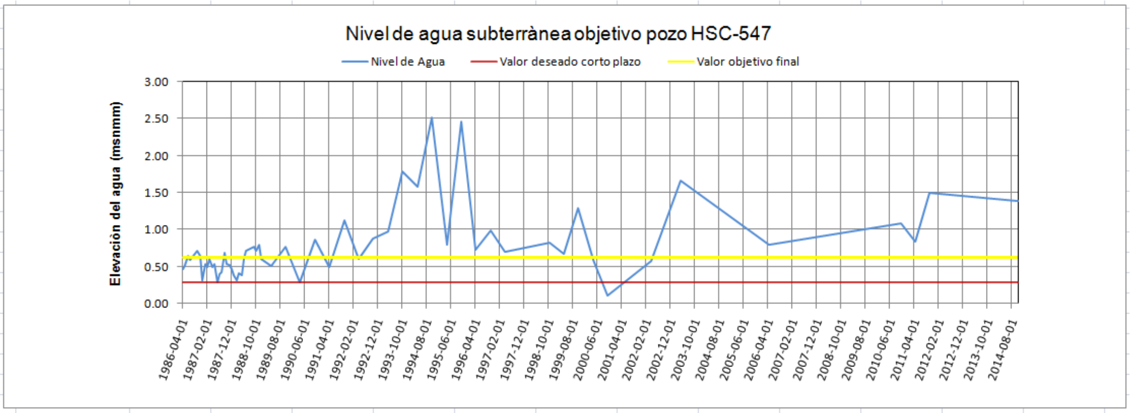

Figure 4-17: HSC-547

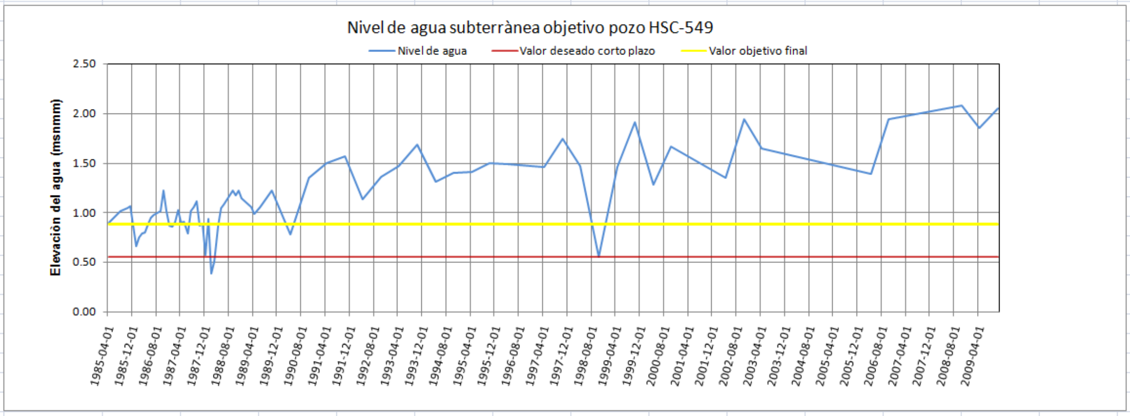

Figure 4-18: HSC-549

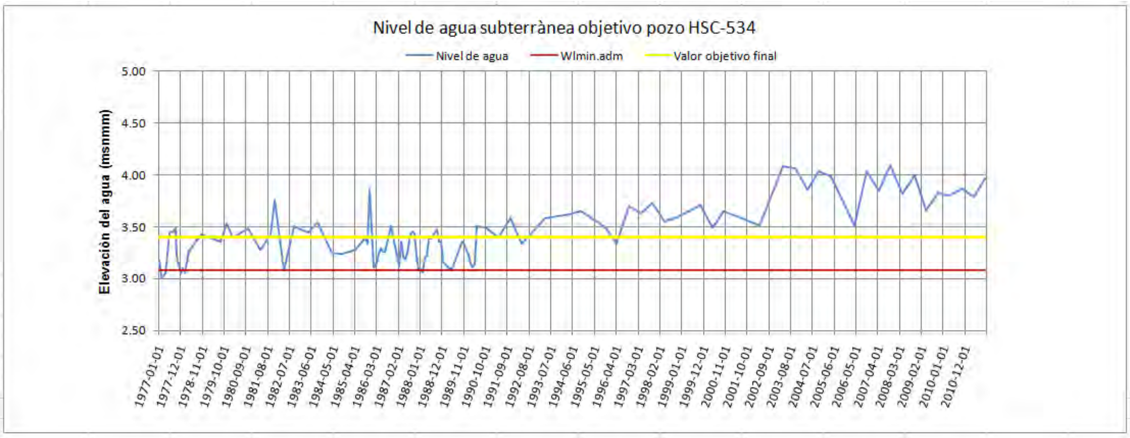

Figure 4-19: HSC-534

4.3 Target Value of Groundwater Quality

The target value of quality will give the possibility of establishing controls on it at all times for which it is important to achieve several key aspects, among which the following can be highlighted:

a)- Water quality control
b)- Carry out a comprehensive analysis of the data
c)- Detect technical and pollution problems from the results, checking the certainty of laboratory information
d)- Develop and implement conservation measures to ensure the good condition of water quality and the health of users

a. Selection of study elements

The elements to be incorporated for the continuity of the Project, from the lessons and capacity enhancement, once completed the activities corresponding to 2016, the following can be determined:

Table 4-2: Indicators of groundwater quality

pH	{U}	NO_2 (*Nitrite*)	{mgL^{-1}}
TDS (*Total Dissolved Solids*)	{mgL^{-1}}	NO_3 (*Nitrate*)	{mgL^{-1}}
Cl (*Chloride*)	{mgL^{-1}}	SO_4 (*Sulfate*)	{mgL^{-1}}
Na (*Sodium*)	{mgL^{-1}}	Ca (*Calcium*)	{mgL^{-1}}

b. Selection of study wells

The following map shows locations of selected monitoring well for groundwater quality. The wells have accumulation of the past monitoring data and show typical condition of the surround environment. Besides, the selection of monitoring wells should be updated and make a choice in response to monitoring purpose, trend of groundwater quality, anthropogenic contamination, etc.

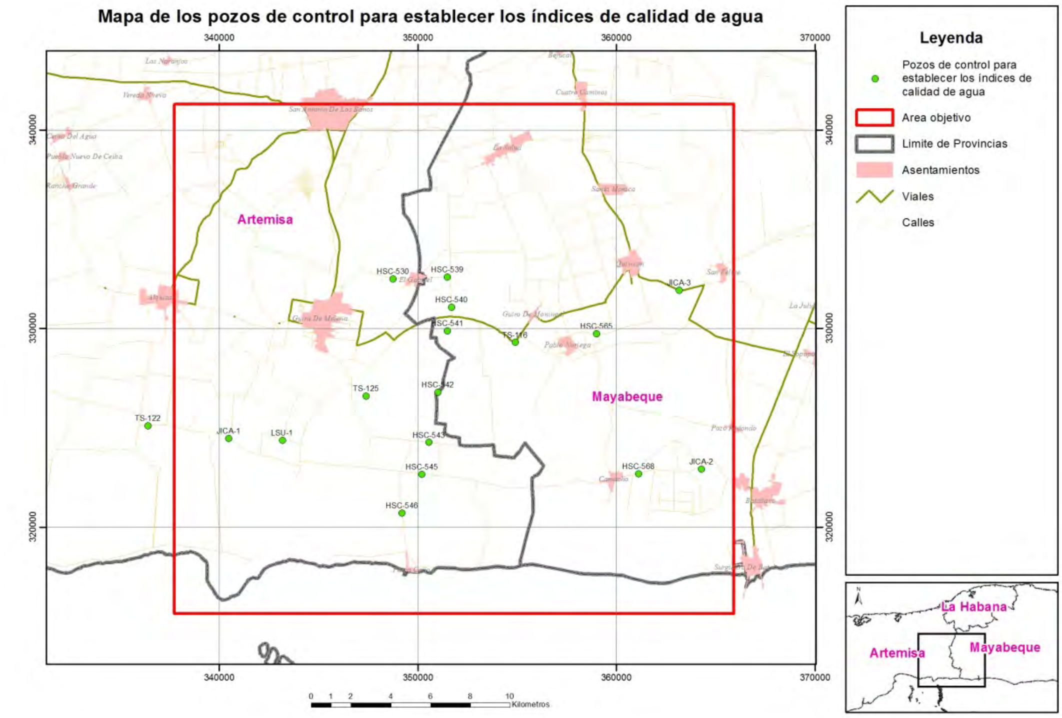

Figure 4-20: Location map of target observation wells (Groundwater quality)

c. Establishing an index value and a target value

c.1 Index value

In this regard, the maximum permissible value will be considered, in order to achieve water quality and, above all, to establish the necessary controls to achieve the overall goal of preserving public health and welfare. It was elaborated from the elements regulated by the NC 1021: 2014 Standard.

Table 4-3: Index Value for water for human consumption

pH	6,5 – 8,5	NO_2 (*Nitrite*)	0,3
TDS (*Total Dissolved Solids*)	1000	NO_3 (*Nitrate*)	45
Cl (*Chloride*)	250	SO_4 (*Sulfate*)	400
Na (*Sodium*)	200	Ca (*Calcium*)	200

Table 4-4: Index value for irrigation

pH	6,5 – 8,5	NO_2 (*Nitrite*)	0,3
TDS (*Total Dissolved Solids*)	1000	NO_3 (*Nitrate*)	45
Cl (*Chloride*)	250	SO_4 (*Sulfate*)	400
Na (*Sodium*)	200	Ca (*Calcium*)	200

c.2 Target values for the conservation of groundwater quality

Tables 2-13 and 2-14 show the statistical calculations of the data of the 49 stations in the 2006-2015 periods, among which the mean, standard deviation, median, minimum and maximum values were obtained. From these we decided that as target conservation values can be used the values of the median as shown in Table 4-5 and Table 4-6.

Table 4-5: Target conservation values for the groundwater quality of the Mayabeque province

Estación	Municipio	Coordenadas		T	Ce	pH	NO_3^{-1}	CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-1}	Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	SDT	CT	CTT
		X	Y	(ºC)	mS/m	u	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	NMP 1000^{-1}	NMP 1000^{-1}
Aguacata	Quvicán	363530	336780	24,4	71,2	7,20	11	0	385	26	19	81	32	18	10	580	2,0	2,0
Arroyo Govea (Superficial)	Bejucal	353700	345925	24,3	96,0	7,55	9	0	437	66	33	119	12	50	9,6	709	2,0E+04	8,8E+04
Buena Ventura	Bejucal	358568	339470	23,7	68,7	7,21	35	0	348	25	11	124	8	13	1,1	567	2,0	2,0
Camacho	Batabanó	359800	322940	25,3	893,0	7,20	20	0	360	92	29	99	23	53	3,3	662	2,0	2,0
CN Biopreparados	Bejucal	355854	346322	24,7	67,1	7,09	15	0	351	28	21	126	5	13	1,2	555	2,0	2,0
Cuatro Caminos	Quvicán	358724	340972	23,9	58,5	7,16	17	0	348	15	10	117	4	8	0,9	558	2,0	2,0
Cuenca Sur UB-2	Quvicán	353039	330307	24,2	63,6	7,32	16	0	314	25	19	104	12	17	1,9	528	2,0	2,0
Cuenca Sur UB-18	Quvicán	361670	335320	23,7	65,9	7,23	14	0	354	20	17	101	13	16	1,4	540	2,0	2,0
Fructuoso Rodriguez	Quvicán	359187	332863	23,9	66,9	7,31	17	0	314	25	20	105	12	17	1,8	527	4,0	2,0
Güiro Boñigal	Quvicán	356243	334668	23,1	63,0	7,33	16	0	299	34	15	90	8	11	1,8	489	2,0	2,0
Gúiro Marrero	Quvicán	358912	328813	22,9	97,8	7,23	20	0	351	113	32	105	21	55	3,6	674	12,5	2,0
ITH Liliana Dimitrova	Quvicán	358368	338721	24,1	60,1	7,21	0	0	333	0	0	120	4	12	1,4	473		
Lily	Bejucal	356058	346322	24,2	65,6	7,13	19	0	345	21	0	121	4	11	0,9	525	2,0	2,0
Manuel Fajardo	Quvicán	351355	334976	23,9	57,8	7,45	19	0	299	23	18	102	7	10	2,1	477	3,0	2,0
Mi Retrio	Quvicán	355440	339466	24,0	58,2	7,36	30	0	269	17	18	100	4	8	2,7	446	2,0	2,0
Ñancaguasu 3	Batabanó	368850	321830	23,9	71,6	7,35	16	0	369	31	37	83	32	20	1,1	580	2,0	2,0
Pablo Noriega	Quvicán	357618	329369	22,7	57,7	7,47	18	0	287	20	0	100	7	10	0,9	449	24,0	2,0
Paradero	Quvicán	361506	335170	23,9	61,0	7,21	7	0	348	17	14	102	11	10	1,0	520	3,0	2,0
Pedrosa	Batabanó	365000	323400	25,1	72,3	7,34	20	0	378	32	24	99	28	21	2,3	584	6,6	2,0
Pesca Habana	Batabanó	366650	318160	24,9	78,8	7,34	14	0	381	38	33	93	27	37	1,8	624	2,0	2,0
Pozo Redondo	Batabanó	365950	325300	24,4	80,3	7,26	5	0	378	35	37	90	34	28	1,8	642	2,0	2,0
Rancho Recre0-1	Bejucal	357413	342425	24,1	67,0	7,05	21	0	375	17	23	126	5	10	2,6	566	3,0	2,0
Rancho Recreo-2	Bejucal	357751	342465	24,1	73,6	7,02	31	0	381	28	22	132	5	13	8,2	609	2,0	2,0
Raúl Garcia	Quvicán	365436	332855	23,6	69,4	7,33	21	0	382	25	24	95	29	21	8,2	596	2,0	2,0
San Agustín	Quvicán	359418	327325	22,9	106,9	7,35	14	0	369	162	43	95	31	89	4,8	787	2,0	2,0
San Vicente	Batabanó	358655	340985	24,8	74,3	7,28	16	0	384	39	31	87	30	32	3,0	622	2,0	2,0
Santa Margarita	Bejucal	358408	342172	23,6	61,9	7,19	19	0	336	25	13	114	3	13	1,0	525	12,5	2,0
Santa Mónica	Quvicán	359786	337012	23,6	59,5	7,17	9	0	323	18	0	108	4	10	0,9	475	4,0	2,0
Santo Cristo	Quvicán	355497	338893	24,2	58,6	7,45	34	0	284	20	18	104	5	8	2,9	489	6,0	6,0
Yolando González-1	Quvicán	360640	333874	22,4	63,1	7,22	13	0	317	20	15	101	13	11	1,1	489	2,0	2,0
Yolando González-2	Quvicán	360521	334467	22,5	58,0	7,41	15	0	311	21	12	92	10	14	0,8	486	2,0	2,0
Zayas	Batabanó	371177	324473	24,1	69,8	7,31	19	0	366	29	29	90	29	22	1,0	572	2,0	2,0

Table 4-6: Target conservation values for the groundwater quality of the Artemisa province

Estación	Municipio	Coordenadas		T	Ce	pH	NO_3^{-1}	CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-1}	Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	SDT	CT	CTT
		X	Y	(ºC)	mS/m	u	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	NMP 1000^{-1}	NMP 1000^{-1}
AC. Waterloo 1	Artemisa	322950	329900	23,2	76,0	7,29	13	0	342	53	25	116	10	34	2,0	593		
AC. Las 400	Alquizar	337050	331900	23,1	66,0	7,23	30	0	304	34	22	108	8	19	2,9	521		
AC. La Europa	Alquizar	333300	323900	22,5	67,0	7,35	27	0	0	113	0	0	0	63	0,0			
S/N Pulido	Alquizar	336800	329250	23,9	65,7	7,52	35	0	226	36	0	98	8	18	2,4	431		
AC. El Pilar	Artemisa	320170	334250	24,5	66,5	7,24	41	0	0	32	32	0	0	0	0,0			
AC. La Matilde	Artemisa	319380	332110	23,7	80,0	7,12	33	0	403	39	27	131	10	27	5,2	669		
Ac. El Favorito	Artemisa	321900	332900	23,6	63,0	7,38	15	0	329	25	0	110	6	17	3,0	501		
Ac. Güira Nuevo	Güira de Melena	344600	330800	22,8	79,2	7,33	38	0	311	59	35	116	10	31	3,8	606		
Ac. Cachimba	Güira de Melena	346600	327600	22,6	85,5	7,39	40	0	295	74	48	103	16	45	3,9	611		
Ac. Boca de Cajio	Güira de Melena	349150	322300	24,8	150,0	7,32	40	0	258	340	75	110	22	146	6,0	941		
Ac. Vereda Nueva	Calimito	334770	341050	22,3	75,2	7,16	44	0	342	22	20	130	5	11	5,9	584		
Ac. Pueblo Nuevo Ceiba1	Caimito	332400	338500	22,4	70,9	7,29	30	0	351	25	17	119	8	13	3,1	594		
K26W7	Güira de Melena	348900	329400	23,4	90,7	7,72	32	0	331	90	41	110	13	55	3,8	611		
K23G3	Güira de Melena	349375	333525	23,4	81,0	7,61	25	0	302	71	26	110	11	38	3,0	578		
Ac. El Gabriel	Güira de Melena	348800	332600	24,0	103,7	7,39	34	0	296	128	42	110	16	76	3,2	649		
Escuela La Jocuma	Güira de Melena	346250	323050	22,3	178,2	7,57	40	0	305	307	90	92	36	241	16,9	1124		
El Donque	Artemisa	324450	332400	23,1	58,4	7,56	29	0	258	25	14	100	5	10	2,4	439		
Ac. El Viviro (HS3)		317000	333100	24,1	61,7	7,23	15	0	360	18	15	110	10	10	0,9	536		
Ac. Toledo (HS3)		317000	333100	23,9	62,4	7,21	8	0	336	18	15	102	12	11	0,9	499		
Ac. Quebrada (HS3)				24,5	55,0	7,58	1	0	299	19	25	92	7	17	0,8	460		

d. Target value of groundwater use

Quality Assessment (Exploitation Recommendations):

Based on the results of the vertical hydrochemical sampling, and the resulting profiles, the exploitation depths of the groundwater for different distances from the coast are recommended.

Orientation of Profiles

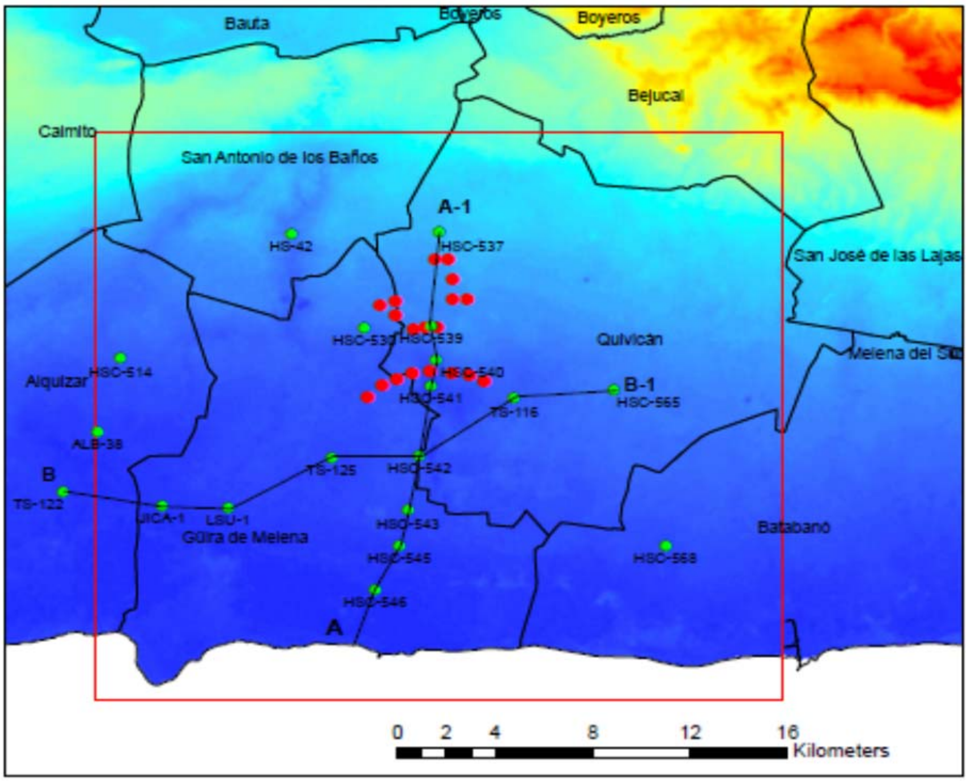

Figure 4-21: Orientation of Profiles

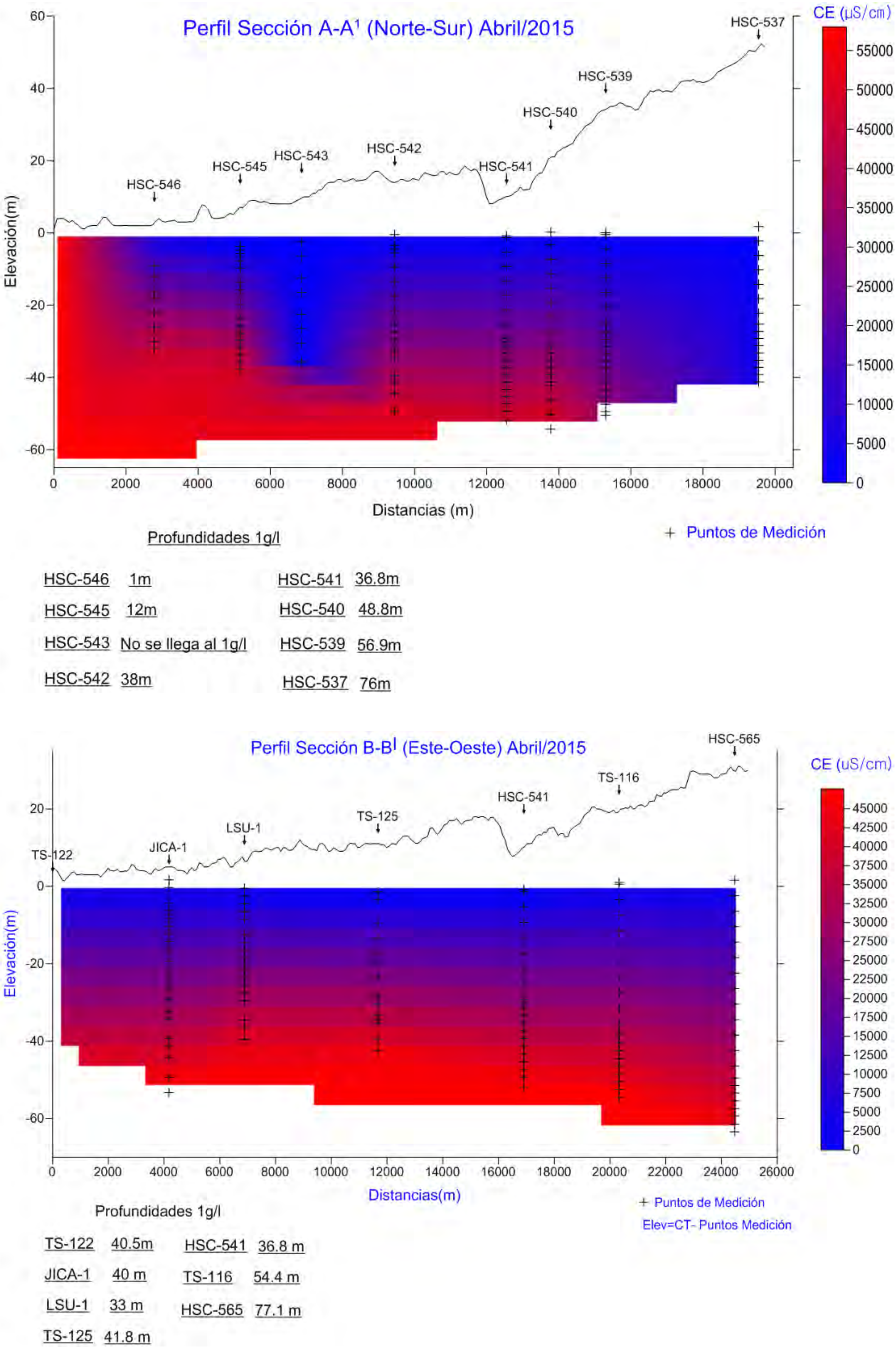

Figure 4-22: Cross-section profiles

Based on the results of the North-South profile, the optimal depths are proposed for the exploitation of groundwater for uses such as:

- Human consumption
- Animal consumption
- Irrigation

Range of Recommended Depths for the Exploitation of Cuenca Sur Groundwater (North-South Direction)

Uses	Recommended Depth Range for Exploitation (m).	Distance from the coast (KM)	Remarks
Human consumption	1m-5m	3	
Animal consumption	1m-5m		
Irrigation	1m-5m		
Human consumption	8m - 12m	5	
Animal consumption	8m - 12m		
Irrigation	8m - 14m		
Human consumption	11m-44m	7	
Animal consumption	11m-44m		
Irrigation	11m-44m		
Human consumption	11m-38m	9	Influence Zone Cuenca Sur Network of Wells
Animal consumption	11m-38m		
Irrigation	11m-38m		
Human consumption	8m-37m	13	Influence Zone Cuenca Sur Network of Wells
Animal consumption	8m-37m		
Irrigation	8m-37m		
Human consumption	18m-49m	14	
Animal consumption	18m-49m		
Irrigation	18m-49m		
Human consumption	32m-57m	15	
Animal consumption	32m-57m		
Irrigation	32m-57m		
Human consumption	47m-76m	20	
Animal consumption	47m-76m		
Irrigation	47m-84m		