CIPREL 5 thermal power plant

hydrogeological study

Version April 15, 2019

A2E - RER- ES

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SUMMARY

VERSION	DESCRIPTION	ESTABLISHED BY	Control (E) THROUGH	APPROVED (E) THROUGH	DATED
V1	STUDY HYDROGEOLOGICAL - Version 15 April 2019	B Canaleta	B Canaleta	B Canaleta	04/15/2019

ARTELIA Water and Environment
Echirolles - TEL: 04 76 33 41 17

1. CONTEXT OF THE PROJECT 5 CIPREL

The future thermal power plant CIPREL 5 is located 1.2 km southeast of the village of Taboth, in the municipality of Jaqueville, and 1 km from the southern edge of the lagoon Ebrié (Figure 1). The nearest residential areas are located approximately 350 meters northwest boundary of the land (camp Bete). Sensitive receptors (human and environmental) identified in this area during the project ESIA studies are:

- resident populations of the village of Taboth, Bete and Matthew camps
- animal species living in the area.

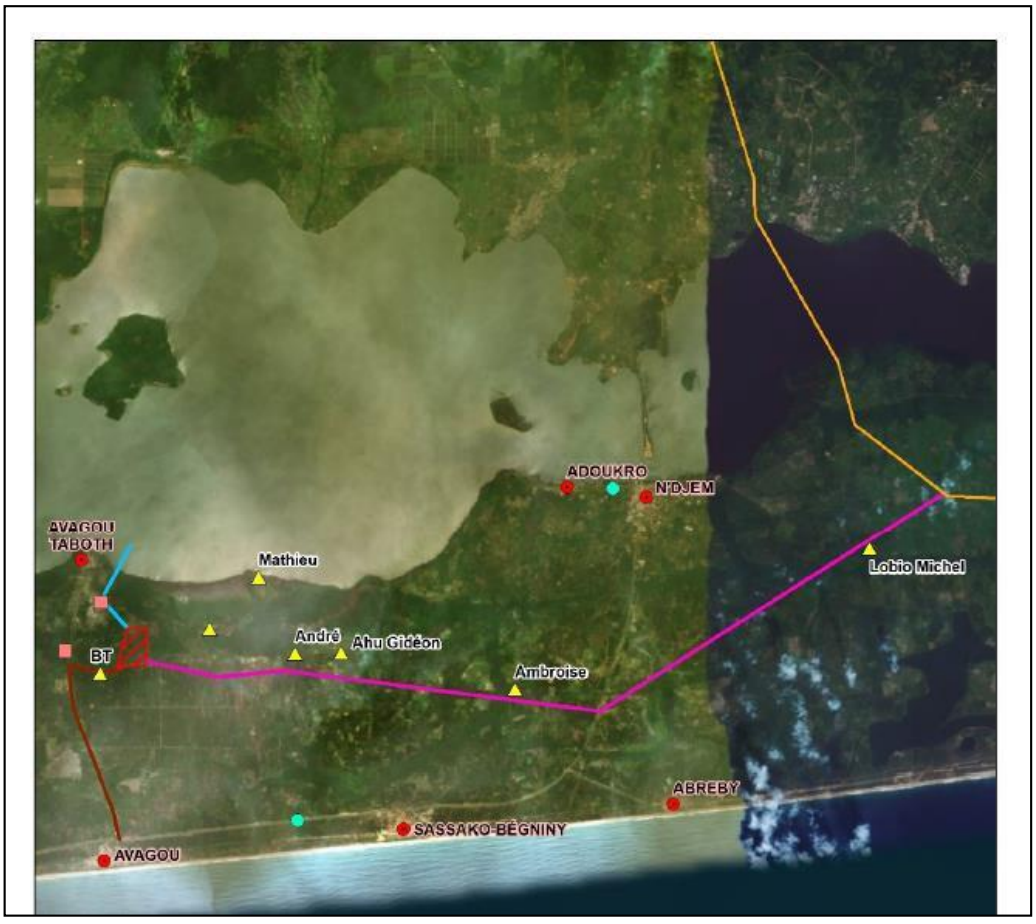


Figure 1 - Project Area 5 CIPREL

A request has been made by IFC regarding a specific hydrogeological study of the area of the future CIPREL 5 power station in order to complete the ESIA study's Hydrogeology component:

"The project will update the impact assessment section based on the results of the hydrogeological tests undertaken on site and on additional groundwater user baseline / census. This will include the results of pumping test to estimate the hydraulic properties of the aquifer and to model drawdown and salt water intrusion according to internationally accepted methods"

2. WATER REQUIREMENTS

The estimated demand for fresh water at the CIPREL 5 thermal power plant are:

- instantaneous flow: 20 m 3 / h
- daily flow: 480 m 3 / day
- Annual flow: 175,200 m 3 / year

It was planned that this flow of fresh water would be taken by means of one or more boreholes in the aquifer present at the site.

3. PURPOSE OF THE STUDY HYDROGEOLOGICAL

The purpose of the hydrogeological study is to characterize the groundwater table and aquifer present at the site right in order to ensure that the samples which will be taken from one or more boreholes, are compatible with the capacities of this table.

For information, the explanatory diagram in Figure 2 allows for the visualization of the incidence of pumping on a flowing water table and on possible works located in the cone of influence of the pumping of a new well or borehole.

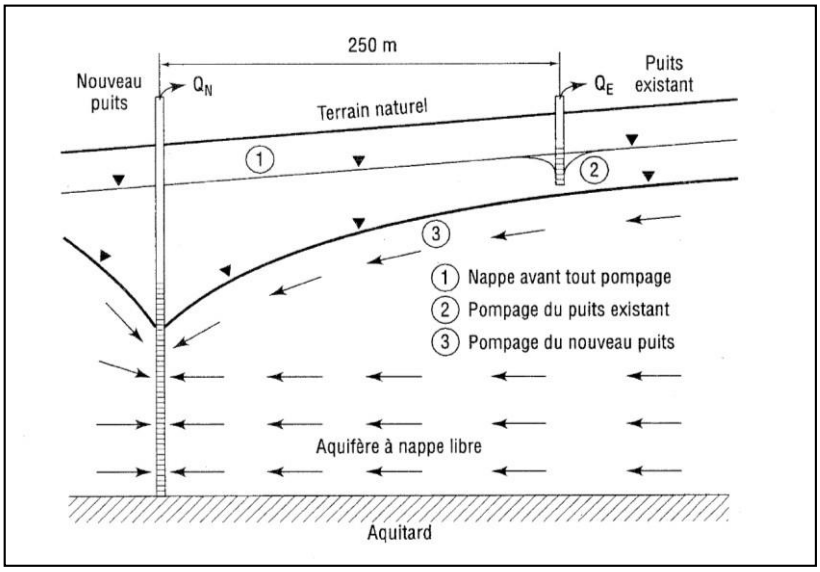


Figure 2 – Representation of the effect of pumping on the groundwater table

Given the proximity of the Ebrié lagoon to the CIPREL site, it is important to ensure that the pumping of the aquifer by drilling does not risk promoting the intrusion of brackish w ater into this aquifer.

An inventory of the use of the Quaternary aquifer around the CIPREL site must also be undertaken in order to identify the local rural communities who use this aquifer for domestic needs. A first hole was drilled in February 2019 by the FORACO company on the site. Pumping tests were carried out on this borehole (sequential flow test, 72 hour long pumping tests). Three water analyses were carried out on samples taken during the long-term pumping test. The results of the tests carried out on this borehole made it possible to acquire the basic data necessary for the characterization of the aquifer and the evaluation of its exploitable potential by drilling.

4. REGIONAL GEOLOGICAL FRAMEWORK

The CIPREL 5 thermal power plant is located on the Jacqueville town near the village of Taboth. The site is positioned on the geological map area in Figure 3.

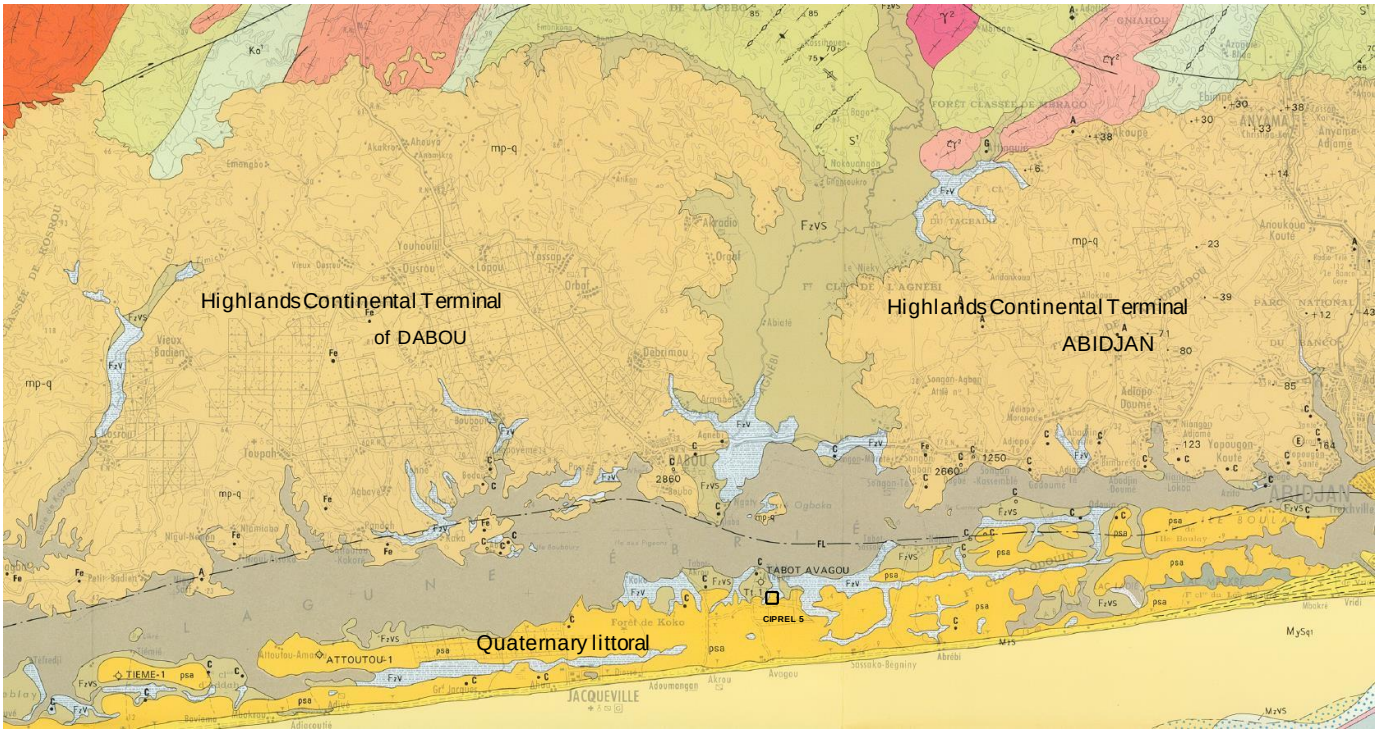


Figure 3 - Extract from the geological map of Abidjan and DABOU - Site Location CIPREL 5

Comments on the regional geological setting

North of the Ebrié lagoon lie the clay-sandy tabular formations of the Continental terminal, designated by the name of Hauts-plateaux of which some rare witnesses are preserved at the level of the islands of the lagoon. These formations contain powerful aquifers exploited for the water supply of Abidjan, Dabou and all the semi urban and rural agglomerations located on the plateaus.

South of the lagoon between Grand Bassam and Jacqueville, we find the Quaternary coastal formations differentiated into 3 groups:

- low-lying sandy-clay plateaus (10 to 15 meters maximum) or Low plateaus ("psa" on the geological map),
- A series of sandbars more or less parallel to the coast and whose altitude ranges from 1.5 to 6 meters rarely reaching higher altitudes (M_2 S on the map),
- deltaic areas and, on the coast of lagoons and in depressions, leached sands or marshy areas (F2V and F2VS on the map)

The CIPREL project is located on the coastal formations of the Lower plateaus ("psa") deposited during the Quaternary Period

An illustrative geological section of the structure of the sedimentary basin and the aquifers of the Continental Terminal and the Quaternary is presented in figure 4. The CIPREL drilling is located on the section at the level of the low lands.

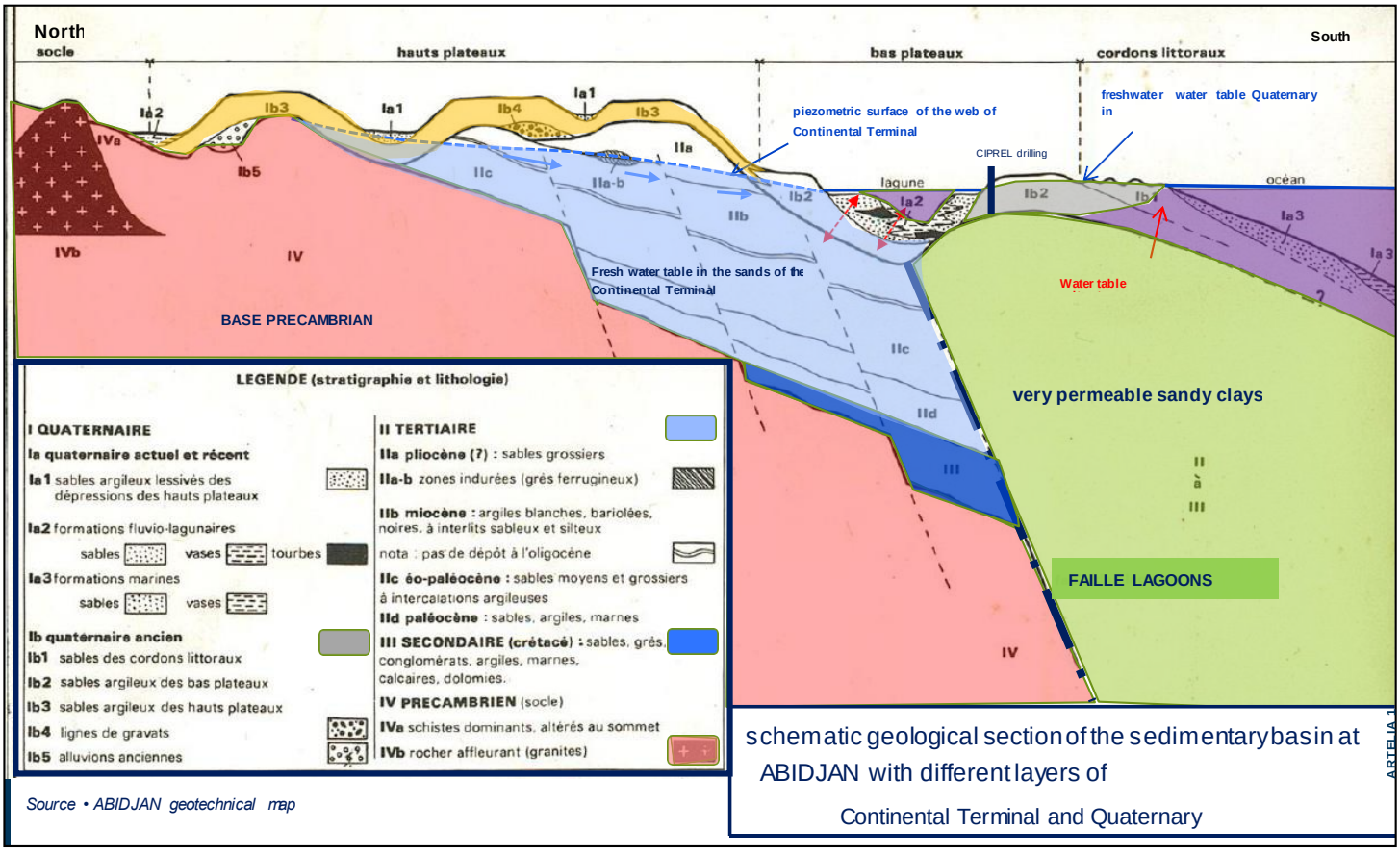


Figure 4 - schematic geological section of the structure of the Ivory Coast sedimentary basin and aquifers Continental Terminal and Quaternary

The Low-lying lands lay above the Quaternary formation

A set of low-lying plateaus (10 to 15 m) extends south of the lagoons. This unit is made up of ocher clay sands up to 15 to 30 meters thick, lying in the Abidjan and Dabou region on the upper Miocene marine consisting of predominantly clay formations.

These plateaus appear as massive bands separated by low marshy areas, lagoon arms or interior lakes of preferential North-South or East-West directions.
A reference geological section of the Quaternary littoral formations was established by JP TASTET (Figure 5 below).

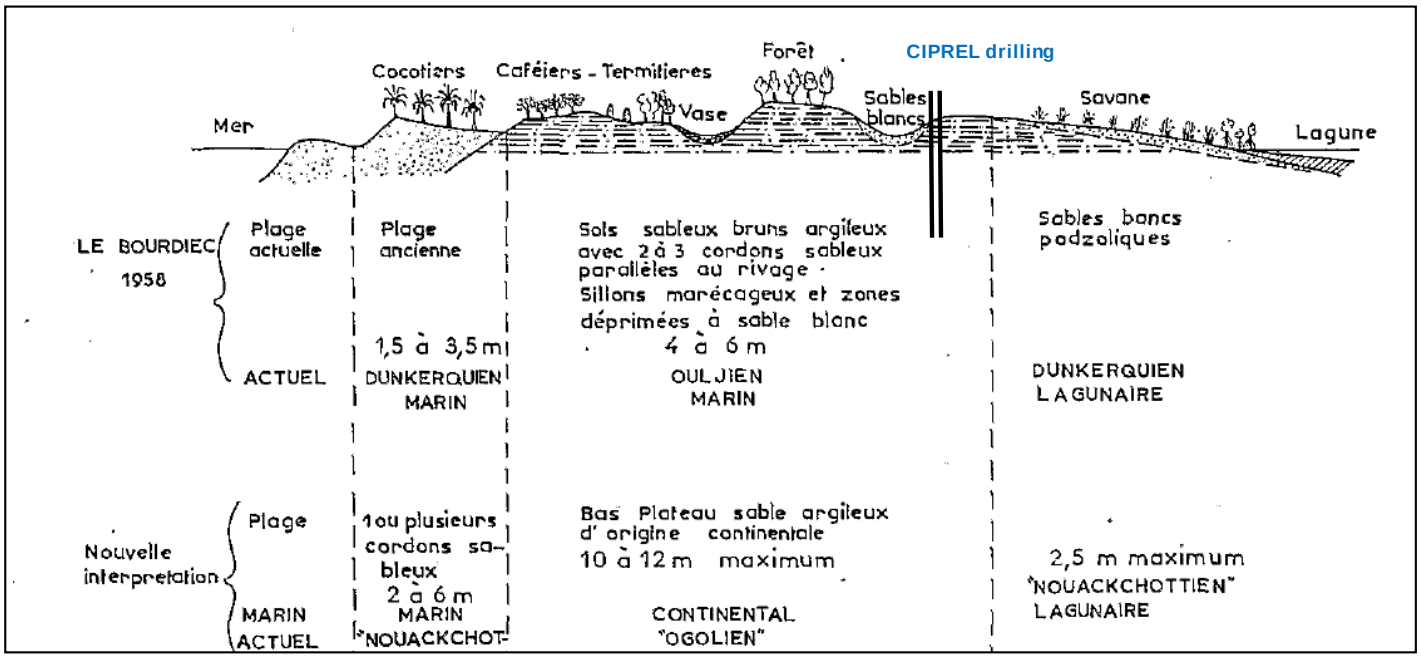


Figure 5 - geological formations Cup Quaternary (source TASTET JP)

The sandbars

South of the lower plateaus, separated from them by a clear drop of a few meters, extend parallel sandbars, oriented East-West, whose altitude varies from 2 to 6 meters. The width of this system of bars is variable. The system is no more than 400 meters west of Lac Bakré and is gradually decreasing to form a single bead. Towards the East it believes and reaches its greatest extension between Vridi and Grand-Bassam.

Lake and River Formations of the Quaternary

Low marshy areas, arms of the lagoon or lakes, cut the Low plateaus.

These low areas form mud flats with swamp forest. In these depressions, fine sands, vases and peat were deposited during the recent Quaternary (Holocene). These depressions filled with clay participate in the drainage of surface water on the edges of the plateaus.

These recent formations have mediocre geotechnical characteristics compared to the sands of the Lower plateaux of the ancient Quaternary.

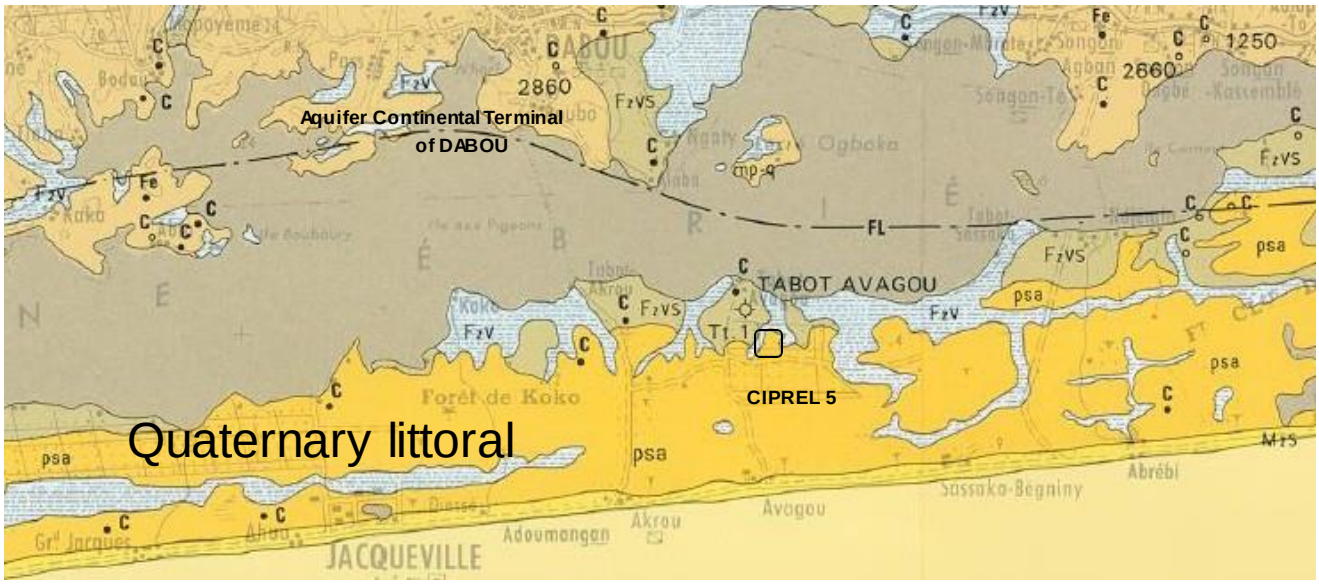


Figure 6 - Site Location CIPREL on a geological map extract

The CIPREL site has been positioned on the extract of the geological map in Figure 6. The geological map shows that the area of influence of the CIPREL project is located largely on a low plateau of the old Quaternary (psa) bordered to the east and to the west by two shallows. It is an old hydrographic network dug during the Quaternary which was gradually filled by recent clay alluvium (F2V). These lowlands are currently used as drainage areas for surface water during heavy rains. On the plateaus of ocher sand soils, the rainwater flows little and infiltrates easily to supply a groundwater table close to the ground.

5. HYDROGEOLOGICAL Characterization of the Aquifer

5.1. INVESTIGATIONS CONDUCTED

An initial soil survey was conducted in June 2018 by the office of geotechnical LABOGEM. A core sampling from a depth of 20 meters and 2 Pressuremeter tests were performed (see Figure 7 the location of surveys and drilling with respect to the project area).

ERANOVE entrusted the first borehole to FORACO in February 2019. It was positioned 1,300 m from the southern edge of the Ebrié lagoon.

Pumping tests were undertaken on this borehole as well as a series of 3 water analyzes during the long-term pumping of the borehole (72 hours). A technical file on drilling and on the results of pumping tests has been established by FORACO.

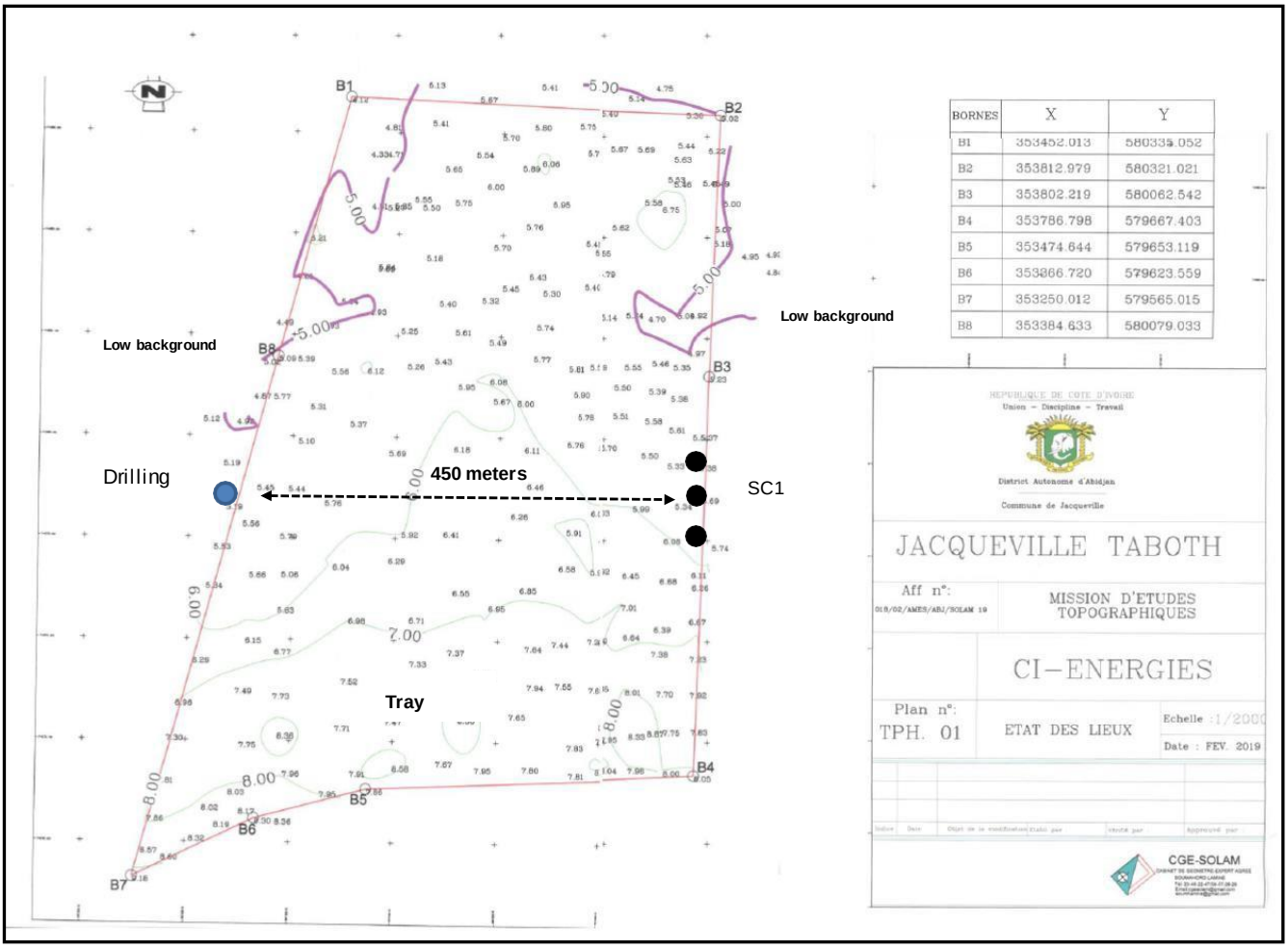


Figure 7 - right area of the central CIPREL with surveying

5.2. GEOLOGICAL FORMATIONS RECOGNIZED THE RIGHT SITE

The geological sample lifted from the core SC1 LABOGEM is as follows:

- Fine, sandy, blackish clay: 0 to 0.50 m
- Fine, sandy, brownish clay: 0.50 to 3.00 m
- Fine, sandy, beige clay: 3.00 to 8.00 m
- Fine, sandy, yellowish clay: 8.00 to 11.00 m
- Medium, sandy, beige clay 11.00 to 14.00 m
- Medium, clean yellowish sand: 14.00 to 15.30 m
- Medium, clean, reddish sand: 15.30 20 m.

Photography courses taken samples is shown in Figure 8. The gradation sands between 11 and 20 meters depth are presented in Figure 9.

Figure 8 - Photographs of soil samples taken during coring

The 2 boreholes with pressuremeter tests (SP1 and SP2) went down to 20 m deep, with geological sections highlighting clean, slightly clayey sands up to the stop depth of the holes.

During LABOGEM's intervention on the site in June 2018, the water levels were raised in the boreholes between 0.30 and 0.70 m deep. These geotechnical soundings revealed the presence of an almost flush aquifer compared to the level of natural terrain (NT) during the month of June 2018 (June is usually the rainiest month in the South of the Ivory Coast). The geological section of the SC1 core drill hole is presented in Figure 10.

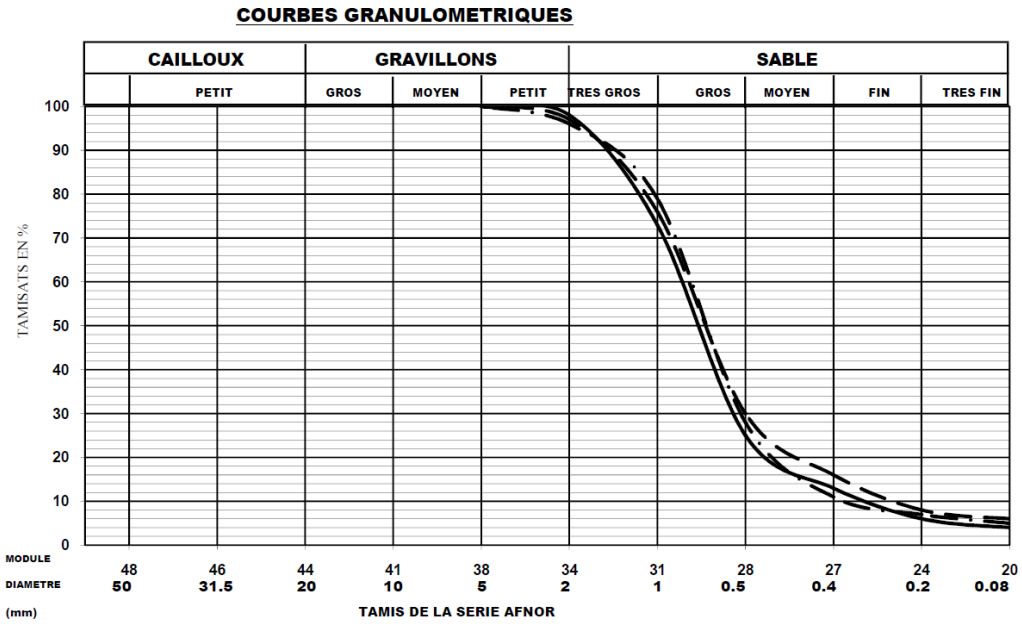


Figure 9 - size curves of sand between 11 and 20 meters

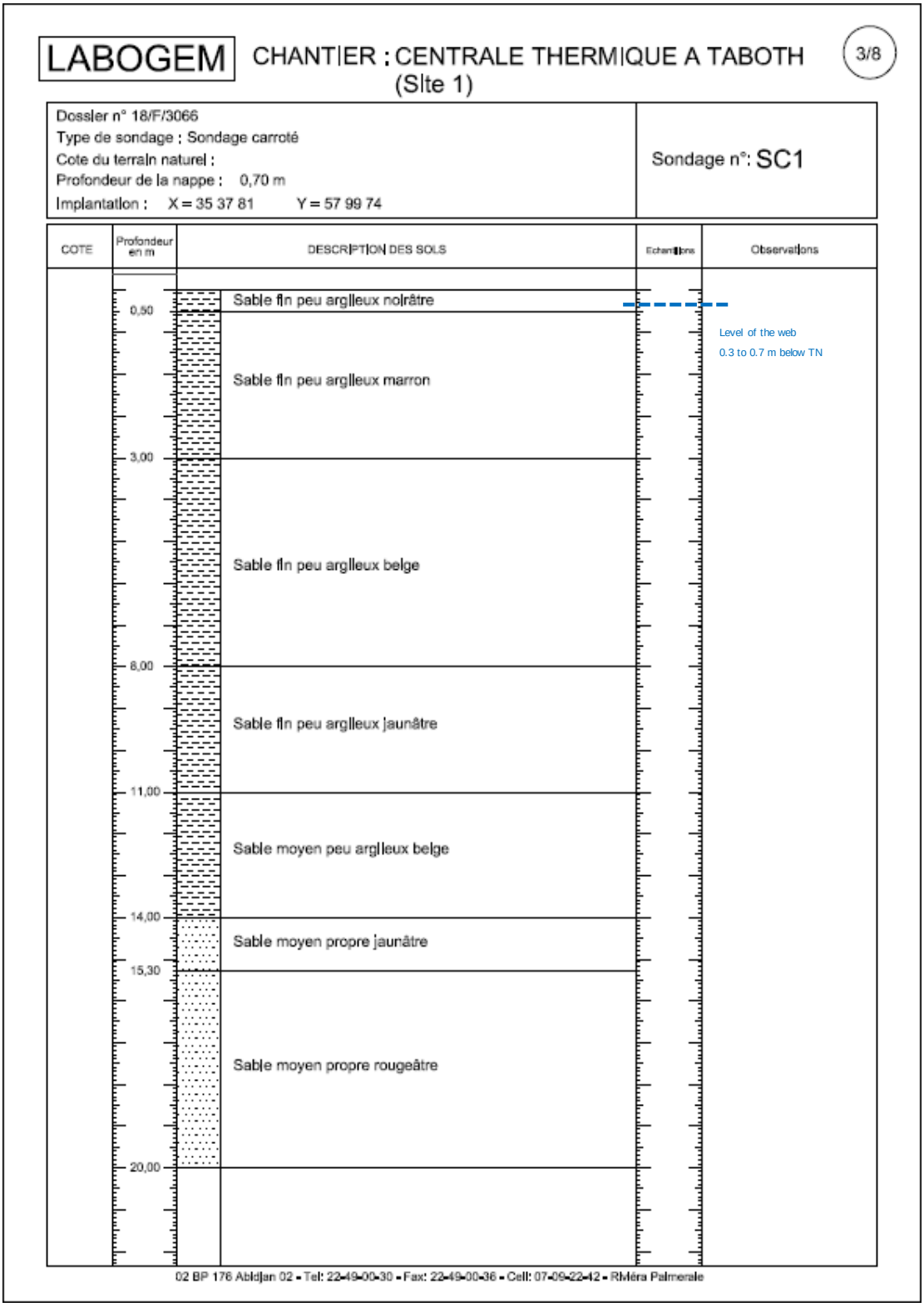


Figure 10 - geological core sampling Cup SC1 (*source LABOGEM)*

5.3. DRILLING DATA from FORACO

The FORACO borehole is located 450 m from the geotechnical boreholes (see Figure 7), and 1300 m from the southern edge of the Ebrié lagoon.
The drilling was done by a mud rotary with a tricone bit; it is a so-called "destructive" drilling method which does not allow the raising of geological sections as precise and reliable as those which can be established from core drilling.

The geological section of the land crossed by the FORACO drilling is presented in Figure 11

0 3 meters _____ fine blackish sands

3-12 meters _____ sandy clay

12 18 meters _____ clean coarse sands

18-30 meters _____ clay

The drilling intersected the same layer of clean medium sands as that recognized by the SC1 core sample under a layer of 12 meters of more clayey fine sands.
This layer of clean medium / coarse sand was collected using a 6 ml strainer between 12 and 18 meters deep.
After installation of the collection column, the hydrostatic level of the sand table balanced itself (in March 2019) to a depth of 1.5 m below the level of NTat the level of drilling.
We are in the presence of a watertable which flows into a sandy formation made up of fine, slightly clayey sands up to 12 meters deep, then clean medium / coarse sands with better permeability between 12 and 18 meters. These sands have a characteristic ocher or reddish coloration. Beyond that, the formations become clayey and not very permeable.
The borehole was fitted with a Ø 200 mm PVC collection column, comprising 6 meters of slotted strainers (1 mm slot) positioned in front of the ocher / reddish sands.
A rolled siliceous gravel of 2/5 mm was placed around the collection column to constitute the solid gravel filter.

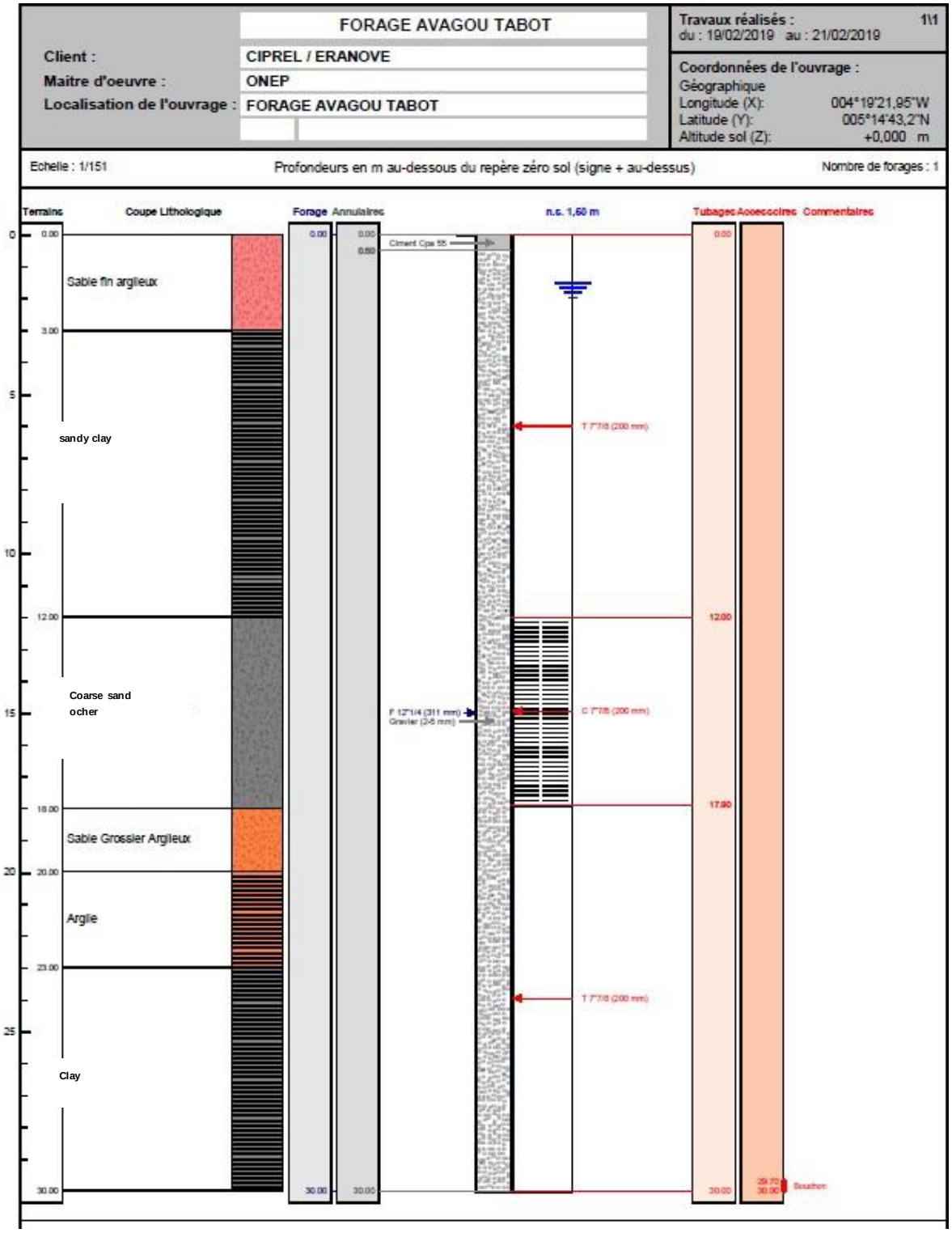


Figure 11 - geological section and drilling technique CIPREL 5 (FORACO folder)

5.4. PUMPING TESTS PERFORMED ON THE DRILLING

Pumping tests were performed of the FORAC drilling

- Step draw dow n tests for a period of 1:30 (15,30,45 and 90 m $_{3}$ / h)
- A long term test (72 hours) at a constant rate of 90 m $_{3}$ / h with monitoring of the water table rise after pumping stops

Figure 12 is an illustrative diagram show ing the draw down of a w ater table around a pumping borehole and the extension of the draw down cone (or depression) of the piezometric surface of the w ater table around the borehole.

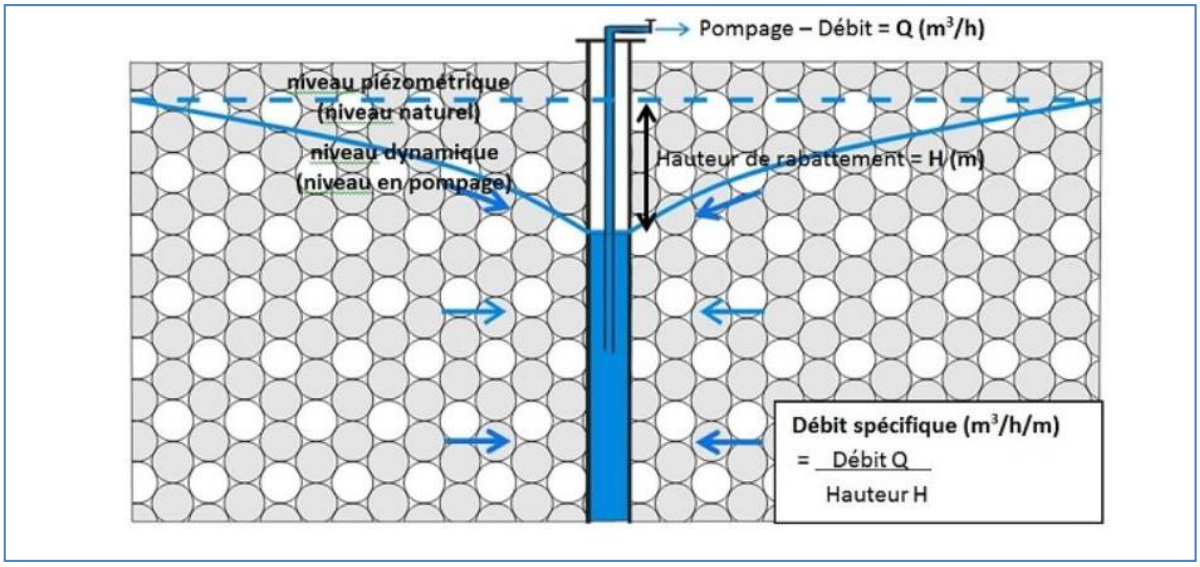


Figure 12 - taper from one ply depression during a pumping test

5.4.1. STEP DRAWDOWN TEST

The results of the step tests (draw downs measured as a function of the pumping rate) have been reproduced graphically in FIG. 13 (established by FORACO)
The 4 flow steps (duration 1 hour 30 minutes) made it possible to measure the follow ing draw dow ns:

Flow rates (m3 / h)	draw down
0	0
15	1.04
30	1.56
45	2.99
90	6.9

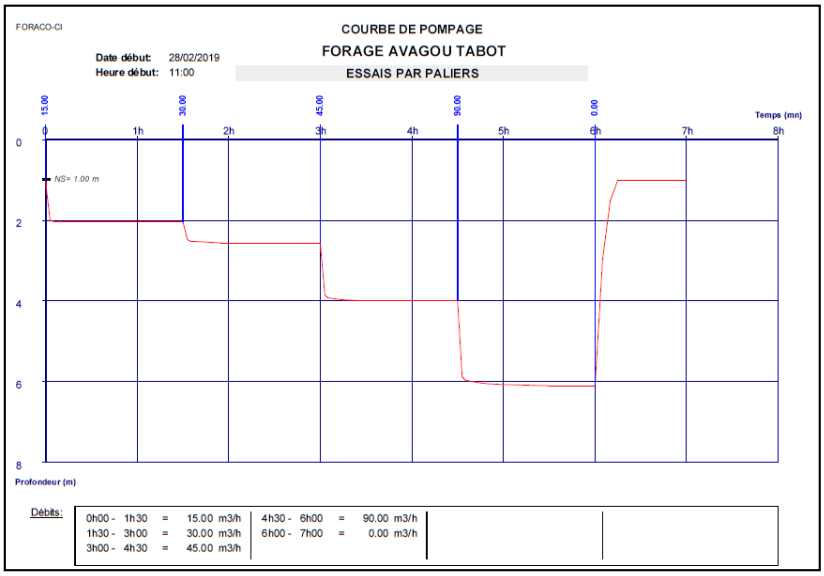


Figure 13 - Testing increments chained rates

5.4.2. DRILLING PRODUCTIVITY

The flow / drawdown measurements made during pumping by flow steps made it possible to establish the characteristic curve of the borehole (Figure 14). This curve makes it possible to deduce the productivity of the drilling (via the values of specific flows), as well as the critical flow not to be exceeded for the exploitation of the drilling.

Flowrates (m3 / h)	drawdown	drawdown (m)	Specific flow (Q / s)
0	0	0	0
15	1.04	1.04	14.423
30	1.56	1.56	19.231
45	2.99	2.99	15,050
90	6.9	6.9	13.043

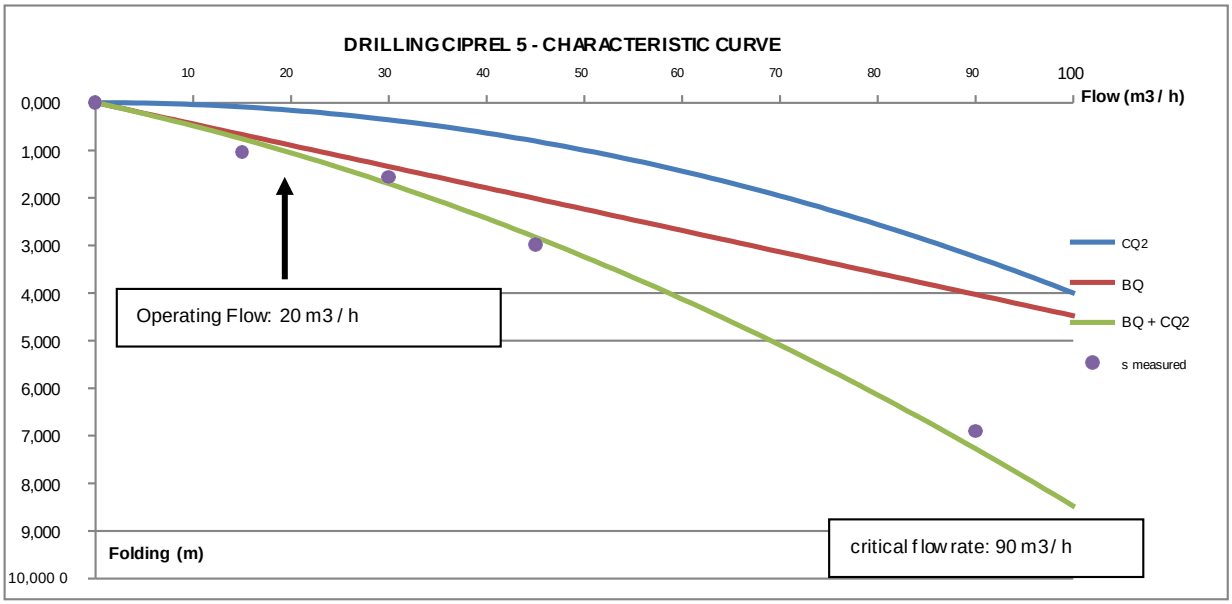


Figure 14 - Characteristic curve drilling - Flow operating / critical flow

Comments on the characteristic curve of drilling and operating speed • 20 m 3 / h

The productivity of the borehole is from 13 to 19 m3 / h / m depending on the specific flows measured during the test This is a relatively high productivity w hich is explained by a good permeability of the sandy layer captured betw een 12 and 18 m and by the low pressure losses observed in the drilling.

Beyond 50 m3 / l the pressure lessens due to the passage of w ater in the gravel / strainer complex of the drilling increase (these so-called quadratic pressure losses are show n by the blue curve on the graph).

At a flow rate of 90 m3 / h, the draw down of the w ater level in the borehole is 6.9 m: 50% of this draw dow n is due to the permeability of the sandy formation and 50% to the pressure losses linked to the passage w ater in the strainers. At this speed, the speed of the w ater in the strainers is too fast:> 5 cm / s it is advisable not to exceed 3 cm / s for the passage of water through the strainers. This flow of 90 m3 / h is the critical flow of drilling.

The operating flow envisaged on the borehole is 20 m3 / h, therefore well below the critical flow of the structure (90 m3 / h).

At a flow rate of 20 m3 / h the draw dow n w ill only be 1.2 m (see Figure 14) w ith little loss of quadratic loads in the structure, and a speed of passage of the w ater in the strainers <to 1.5 cm / s w hich is a very good thing w ith regard to the durability of the structure.

5.4.3. TEST OF LONG TERM PUMPING

A long-term pumping test w as carried out on the borehole at a constant flow rate of 90 m3 / h for a period of 72 hours.

This type of test is called "aquifer test" to assess the transmissivity of the aquifer by measuring the draw dow n of the w ater level on the borehole as w ell as on piezometers arranged around the borehole, to observe the boundary conditions of the aquifer (presence of an impermeable border or recharge) or to highlight the phenomena of drainage betw een aquifers.

During the test, only measurements on the borehole w ere made because there w ere no piezometers around the borehole.

The graph below show s the evolution of the dynamic level of the borehole (w ater level) during the 72 hours of pumping (FORACO document).

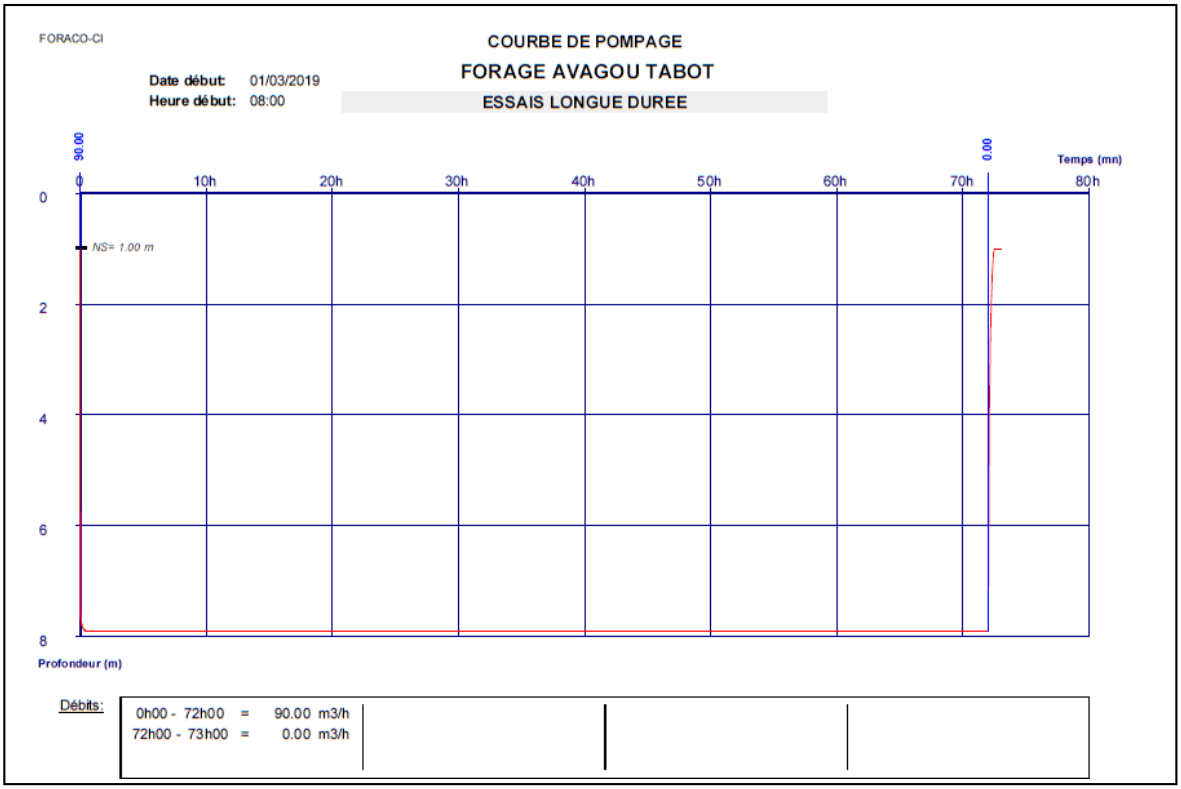


Figure 15 - Measurement of water level achieved during pumping 72 hours

Comments on the results of long-term pumping (start of pumping the 01/03/2019)

Before pumping, the level of the water table was 1 m below the TN.
During pumping at 90 m3 / h, the water level in the borehole was lowered by 6.48 meters after 1 minute of pumping; after 1 hour of pumping the drawdown has stabilized at 6.90, or 7.90 m under the TN.
No fluctuations in the dynamic level (i.e. the water level during pumping) were observed during the 3 days of pumping (see Figure 16 - Semi log representation of long-term pumping).
The results of the pumping tests show that a permanent flow regime is quickly observed on this borehole with stabilization of the drawdown, which is a very good thing for the exploitation of a borehole.
The transient flow phase is very short (1 hour).
After stopping pumping, the level rises very quickly and the borehole recovers its original hydrostatic level in 1⁄2 hour (see Drill file in appendix 1).

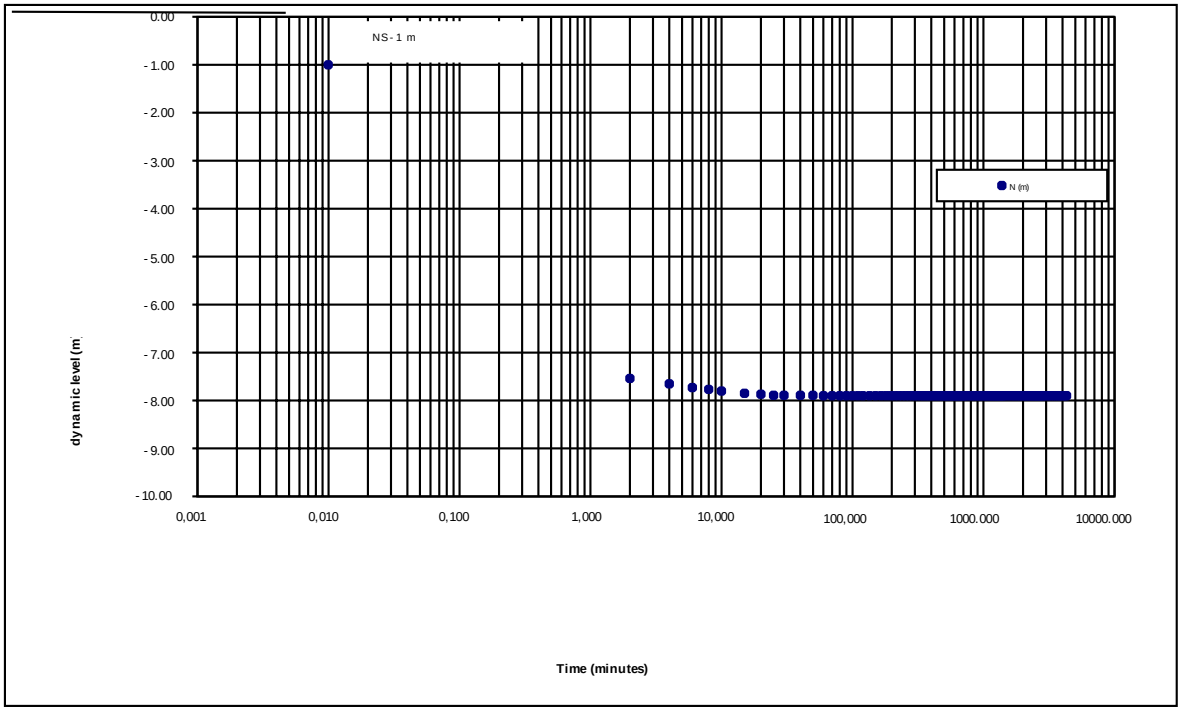


Figure 16 - Representation semi log of long term pumping 90 m $_{3}$ / h

5.4.4. HYDRODYNAMIC PARAMETERS OF THE AQUIFER

Only the measurements made on the pumping borehole are available to determine the hydrodynamic parameters of the aquifer, which are its transmissivity (T) and its storage coefficient (S).

Having no accompanying piezometers around the borehole, it will not be possible to measure the value of the storage coefficient of the aquifer; however the values of S for this type of aquifer are between 0.01 and 0.001.

The transmissivity value cannot be deduced from the transient flow phase which is too short and which would give an overvalued value of this parameter. It would have been necessary to have 3 to 4 accompanying piezometers placed at different distances from the borehole to be able to measure the transmissivity of the aquifer in permanent flow regime.

However, we have the possibility of obtaining an approximate value of this transmissivity from the specific drilling flow: 19 m3 / h / m for a flow of 30 m3 / h with little pressure losses related to drilling, which gives a transmissivity value of 5 x 10-3 m2 / s.

This is a value usually seen in this type of sandy aquifer. We will consider the following hydrodynamic parameters of the aquifer to carry out drilling exploitation simulations, in particular the calculation of its radius of influence::

- Transmissivity of the aquifer (T): 5 x 10- $_{3}$ m $_{2/}$ s
- Sand permeability: 2-3 x 10- $_{4}$ m / s
- storage coefficient of the aquifer (S): 0.005

5.4.5. CALCULATION OF THE RADIUS OF INFLUENCE OF PUMPING ON AQUIFER

The graph below reproduces the extension of the cone of drawdown of the aquifer around the borehole according to the hydrodynamic parameters of the water table T and S.
The cone of drawdown of the aquifer (or cone of piezometric depression) generated by a pumping of 90 m3 / h has a radius of the order of 100 meters around the borehole.

The web of the drawdown cone (or cone piezometric depression) generated by a pump 90 m $_{3}$ / ha a radius of the order of 100 meters around the borehole. Beyond the influence of the pump, drawdown will no longer be measurable.

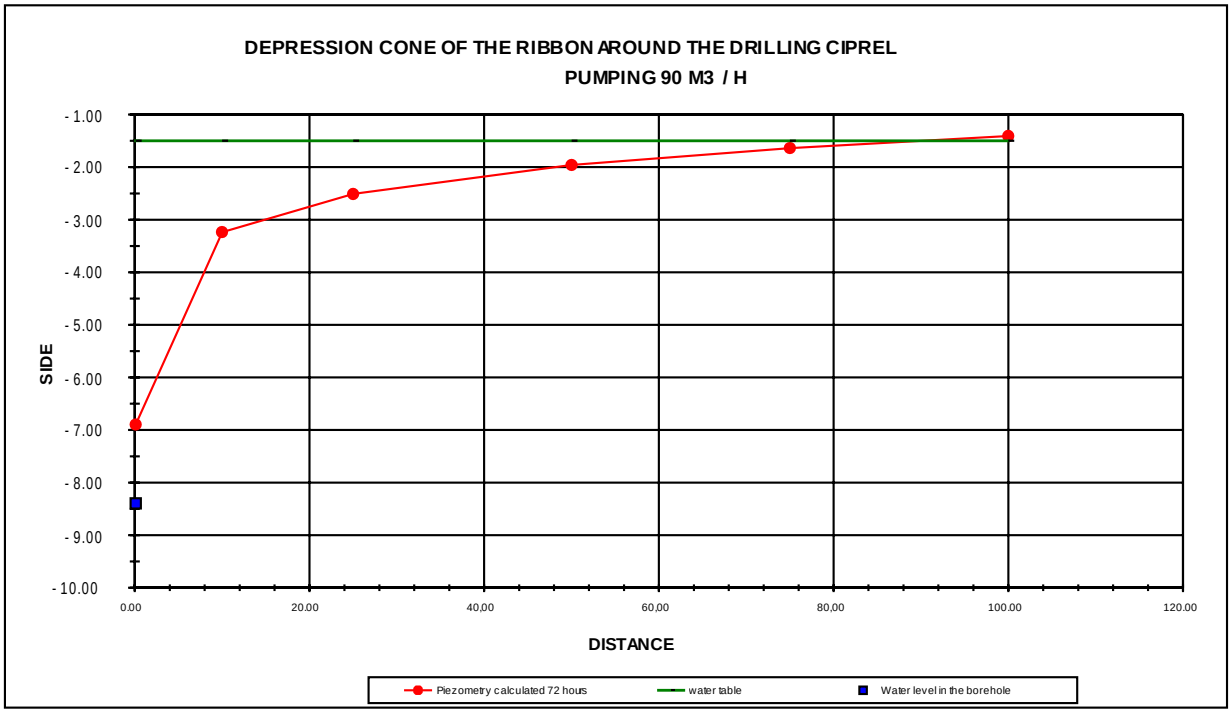


Figure 17 - influence radius of a pump 90 m3 / h on the web

On the graph, the blue dot indicates the w ater level / NT(- 8.4 m) observed in the borehole.

In the absence of quadratic pressure losses (linked to the passage of w ater through the strainers), the w ater level in the borehole w ould be located at - 7 m from the NT red point on the curve. The CIPREL thermal pow er station needs pumping on boreholes w ith a flow rate of 20 m3 / h.

On the graph below (Figure 18), the cone of draw dow n of the aquifer around a borehole pumped at 20 m3 / h has been reproduced.

We can see that the extension of the cone for low ering the w ater table w ill remain limited to a radius of a hundred meters around the borehole.

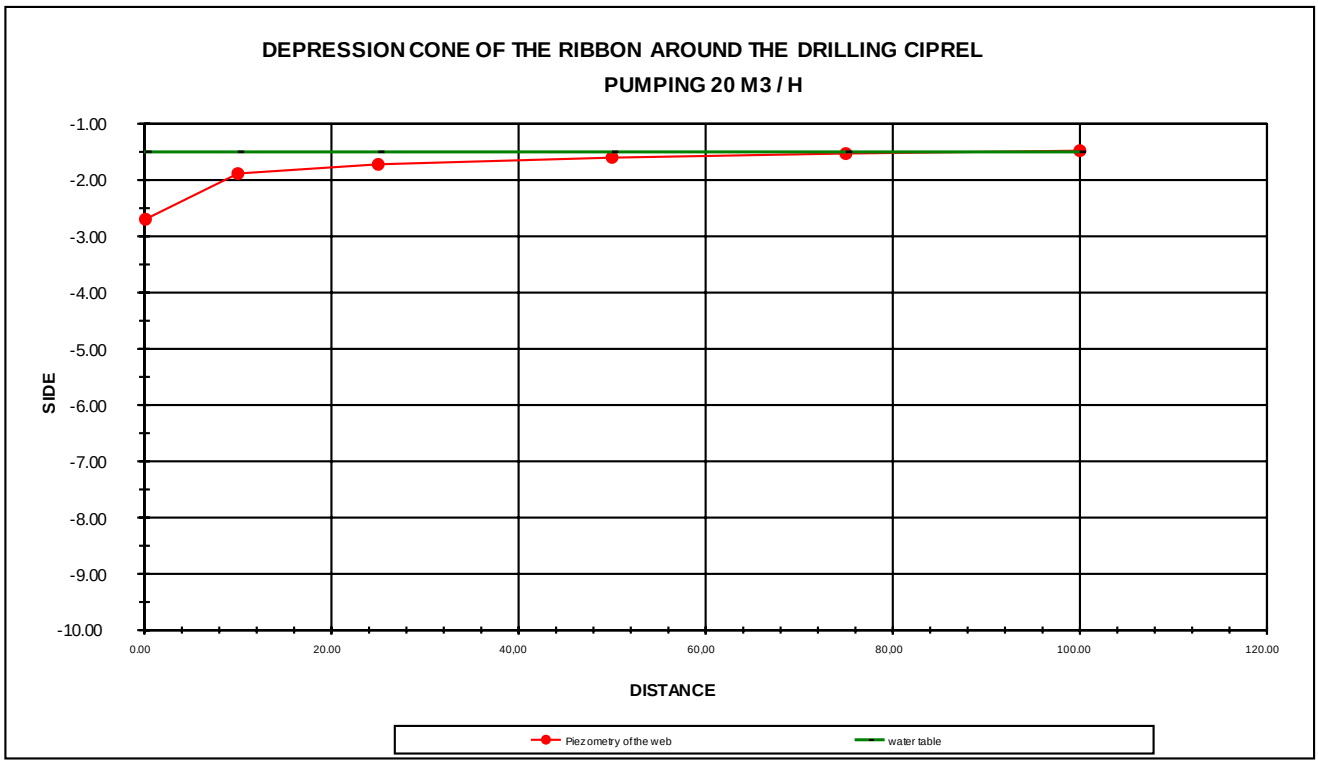


Figure 18 - influence radius of a pump 20 m3 / h on the web

5.5. Piezometric DATA AND DISHCARGE OF THE AQUIFER

In the current state of investigations and drilling carried out on the site, there are only two access points to the aquifer allowing to establish a first piezometric sketch of the aquifer under the CIPREL site (cf. Figure 19).

The 2 points are the FORACO drilling and the SC1 coring of which we know the NGCI (General Levelling Network of Cote D'Ivoire) altimetric dimensions of the NT at the level of the 2 holes.

Groundwater levels were measured on the borehole and on the coring during the construction of the works.

Considering, the NT has an altitude of 5.5 m NGCI on the two survey points, and a water table depth of 1 m compared to the NT the piezometric dimension of the water table at the 2 points is around + 4.5 m NGCI.

From these 2 points, we can draw a first isopièze at + 4.5 m, which indicates a general direction of discharge of the South North aquifer towards the Ebrié lagoon.

To establish a true piezometric map representative of the groundwater flow conditions, it would be necessary to set up a network of piezometers inside and outside the site.

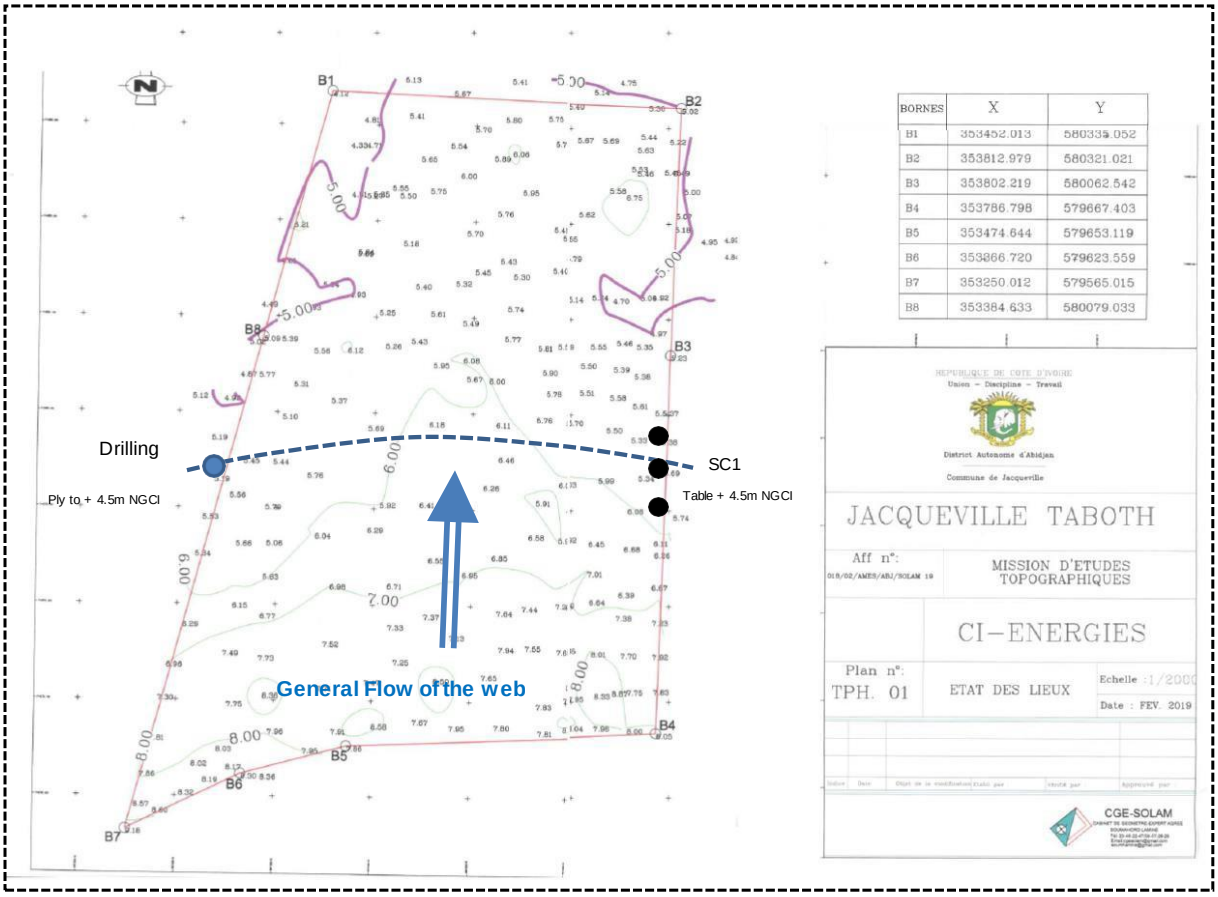


Figure 19 - piezometric sketch indicating a North South flow of the web in the direction of the lagoon Ebrié

5.6. ANALYSES AND WATER QUALITY OF THE RIBBON

Three borehole water analyzes were carried out during long-term pumping (after 24, 48 and 72 hours of pumping). Ebrié lagoon water quality analyzes are also available from water samples taken off Tabot. These analyzes of the waters of the Ebrié lagoon will make it possible to make a comparison with the groundwater of the aquifer.

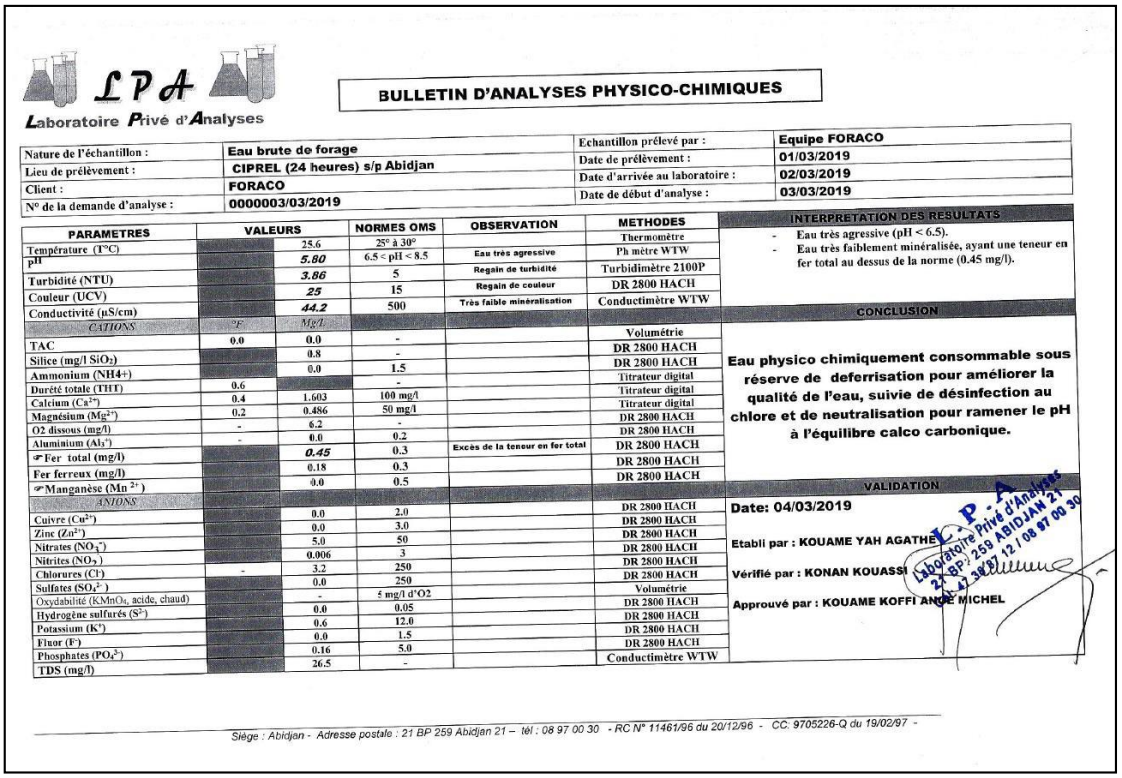
5.6.1. ANALYSIS OF WATER DRILLING

The results of the 3 analyses are presented below. The waters of the aquifer are not very mineralized with an electrical conductivity of 46 µS a TDS (mineralization) of 27.9 mg / l. These are acidic and aggressive waters with a pH of 4.9.

We note the presence of a little dissolved iron (0.4 mg / L) which can generate a slight coloration when water is aerated. We note the absence of ammonium, and a low nitrate content (5 mg / l).

The chloride content is very low: 3.2 mg / L, which indicates that the aquifer waters were not contaminated (during the 72 hours of pumping at 90 m3 / h) by the intrusion of brackish water from the Ebrié lagoon.

Table 1 - Water analysis of drilling after 24 hours of pumping



LPA
Laboratoire Privé d'Analyses

BULLETIN D'ANALYSES PHYSICO-CHIMIQUES

Nature de l'échantillon :	Eau brute de forage	Echantillon prélevé par :	Equipe FORACO
Lieu de prélèvement :	CIPREL (24 heures) s/p Abidjan	Date de prélèvement :	01/03/2019
Client :	FORACO	Date d'arrivée au laboratoire :	02/03/2019
N° de la demande d'analyse :	0000003/03/2019	Date de début d'analyse :	03/03/2019

PARAMETRES	VALEURS		NORMES OMS	OBSERVATION	METHODES
Température (T°C)		25.6	25° à 30°		Thermomètre
pH		*5.80*	6.5 < pH < 8.5	Eau très agressive	Ph mètre WTW
Turbidité (NTU)		*3.86*	5	Regain de turbidité	Turbidimètre 2100P
Couleur (UCV)		*25*	15	Regain de couleur	DR 2800 HACH
Conductivité (µS/cm)		*44.2*	500	Très faible minéralisation	Conductimètre WTW
CATIONS	*°F*	*Mg/L*			
TAC	0.0	0.0	-		Volumétrie
Silice (mg/l SiO_2)		0.8	-		DR 2800 HACH
Ammonium ($NH4+$)		0.0	1.5		DR 2800 HACH
Dureté totale (THT)	0.6		-		Titrateur digital
Calcium (Ca^{2+})	0.4	1.603	100 mg/l		Titrateur digital
Magnésium (Mg^{2+})	0.2	0.486	50 mg/l		Titrateur digital
O2 dissous (mg/l)	-	6.2	-		DR 2800 HACH
Aluminium (Al_3^+)	-	0.0	0.2		DR 2800 HACH
☞Fer total (mg/l)		*0.45*	0.3	Excès de la teneur en fer total	DR 2800 HACH
Fer ferreux (mg/l)		0.18	0.3		DR 2800 HACH
☞Manganèse (Mn^{2+})		0.0	0.5		DR 2800 HACH
ANIONS					
Cuivre (Cu^{2+})		0.0	2.0		DR 2800 HACH
Zinc (Zn^{2+})		0.0	3.0		DR 2800 HACH
Nitrates (NO_3^-)		5.0	50		DR 2800 HACH
Nitrites (NO_2^-)		0.006	3		DR 2800 HACH
Chlorures (Cl^-)	-	3.2	250		DR 2800 HACH
Sulfates (SO_4^{2-})		0.0	250		DR 2800 HACH
Oxydabilité ($KMnO_4$, acide, chaud)		-	5 mg/l d'O2		Volumétrie
Hydrogène sulfurés (S^{2-})		0.0	0.05		DR 2800 HACH
Potassium (K^+)		0.6	12.0		DR 2800 HACH
Fluor (F^-)		0.0	1.5		DR 2800 HACH
Phosphates (PO_4^{3-})		0.16	5.0		DR 2800 HACH
TDS (mg/l)		26.5	-		Conductimètre WTW

INTERPRETATION DES RESULTATS

- Eau très agressive (pH < 6.5).
- Eau très faiblement minéralisée, ayant une teneur en fer total au dessus de la norme (0.45 mg/l).

CONCLUSION

Eau physico chimiquement consommable sous réserve de deferrisation pour améliorer la qualité de l'eau, suivie de désinfection au chlore et de neutralisation pour ramener le pH à l'équilibre calco carbonique.

VALIDATION

Date: 04/03/2019

Etabli par : KOUAME YAH AGATHE

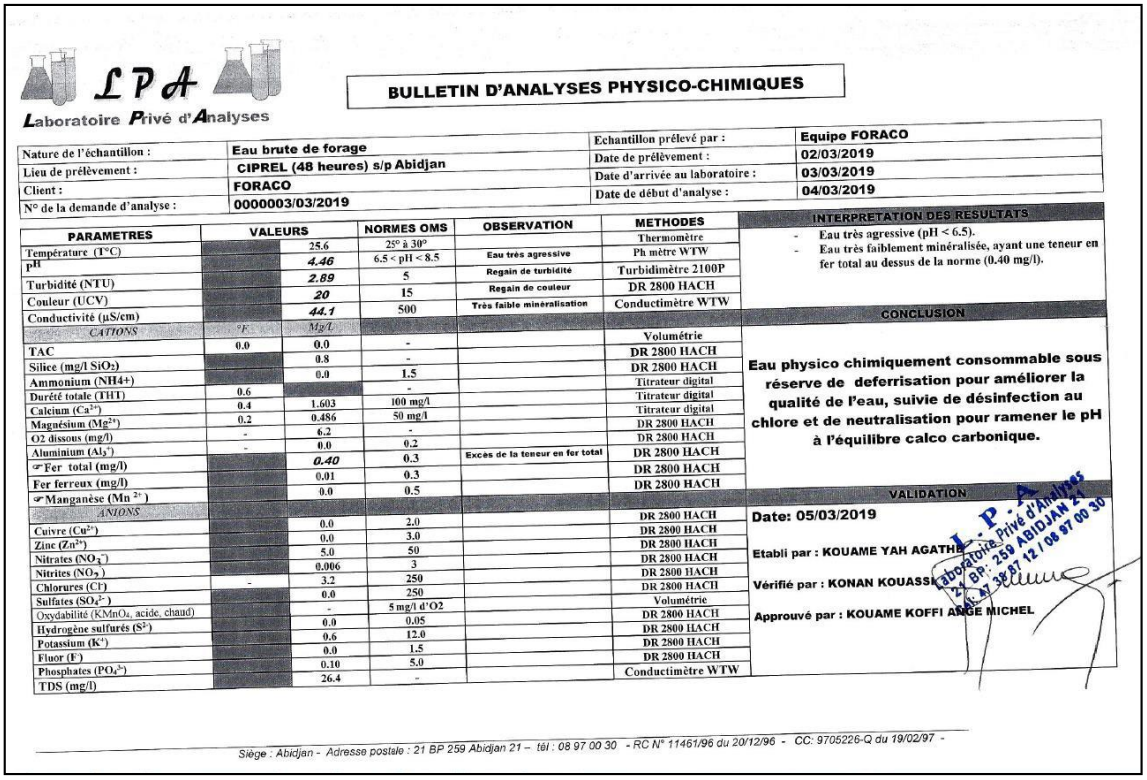
Vérifié par : KONAN KOUASSI

Approuvé par : KOUAME KOFFI ANGE MICHEL

Laboratoire Privé d'Analyses 21 BP 259 ABIDJAN 21 Tél. 27 38 87 12 / 08 97 00 30

Siège : Abidjan - Adresse postale : 21 BP 259 Abidjan 21 – tél : 08 97 00 30 - RC N° 11461/96 du 20/12/96 - CC: 9705226-Q du 19/02/97 -

Table 2 - Analysis of drilling water after 48 hours of pumping



LPA
Laboratoire Privé d'Analyses

BULLETIN D'ANALYSES PHYSICO-CHIMIQUES

Nature de l'échantillon :	Eau brute de forage	Echantillon prélevé par :	Equipe FORACO
Lieu de prélèvement :	CIPREL (48 heures) s/p Abidjan	Date de prélèvement :	02/03/2019
Client :	FORACO	Date d'arrivée au laboratoire :	03/03/2019
N° de la demande d'analyse :	0000003/03/2019	Date de début d'analyse :	04/03/2019

PARAMETRES	VALEURS		NORMES OMS	OBSERVATION	METHODES
Température (T°C)		25.6	25° à 30°		Thermomètre
pH		*4.46*	6.5 < pH < 8.5	Eau très agressive	Ph mètre WTW
Turbidité (NTU)		*2.89*	5	Regain de turbidité	Turbidimètre 2100P
Couleur (UCV)		*20*	15	Regain de couleur	DR 2800 HACH
Conductivité (µS/cm)		*44.1*	500	Très faible minéralisation	Conductimètre WTW
CATIONS	*°F*	*Mg/L*			
TAC	0.0	0.0	-		Volumétrie
Silice (mg/l SiO_2)		0.8	-		DR 2800 HACH
Ammonium ($NH4+$)		0.0	1.5		DR 2800 HACH
Dureté totale (THT)	0.6		-		Titrateur digital
Calcium (Ca^{2+})	0.4	1.603	100 mg/l		Titrateur digital
Magnésium (Mg^{2+})	0.2	0.486	50 mg/l		Titrateur digital
O2 dissous (mg/l)	-	6.2	-		DR 2800 HACH
Aluminium (Al_3^+)	-	0.0	0.2		DR 2800 HACH
☞Fer total (mg/l)		*0.40*	0.3	Excès de la teneur en fer total	DR 2800 HACH
Fer ferreux (mg/l)		0.01	0.3		DR 2800 HACH
☞Manganèse (Mn^{2+})		0.0	0.5		DR 2800 HACH
ANIONS					
Cuivre (Cu^{2+})		0.0	2.0		DR 2800 HACH
Zinc (Zn^{2+})		0.0	3.0		DR 2800 HACH
Nitrates (NO_3^-)		5.0	50		DR 2800 HACH
Nitrites (NO_2^-)		0.006	3		DR 2800 HACH
Chlorures (Cl^-)	-	3.2	250		DR 2800 HACH
Sulfates (SO_4^{2-})		0.0	250		DR 2800 HACH
Oxydabilité ($KMnO_4$, acide, chaud)		-	5 mg/l d'O2		Volumétrie
Hydrogène sulfurés (S^{2-})		0.0	0.05		DR 2800 HACH
Potassium (K^+)		0.6	12.0		DR 2800 HACH
Fluor (F^-)		0.0	1.5		DR 2800 HACH
Phosphates (PO_4^{3-})		0.10	5.0		DR 2800 HACH
TDS (mg/l)		26.4	-		Conductimètre WTW

INTERPRETATION DES RESULTATS

- Eau très agressive (pH < 6.5).
- Eau très faiblement minéralisée, ayant une teneur en fer total au dessus de la norme (0.40 mg/l).

CONCLUSION

Eau physico chimiquement consommable sous réserve de deferrisation pour améliorer la qualité de l'eau, suivie de désinfection au chlore et de neutralisation pour ramener le pH à l'équilibre calco carbonique.

VALIDATION

Date: 05/03/2019

Etabli par : KOUAME YAH AGATHE

Vérifié par : KONAN KOUASSI

Approuvé par : KOUAME KOFFI ANGE MICHEL

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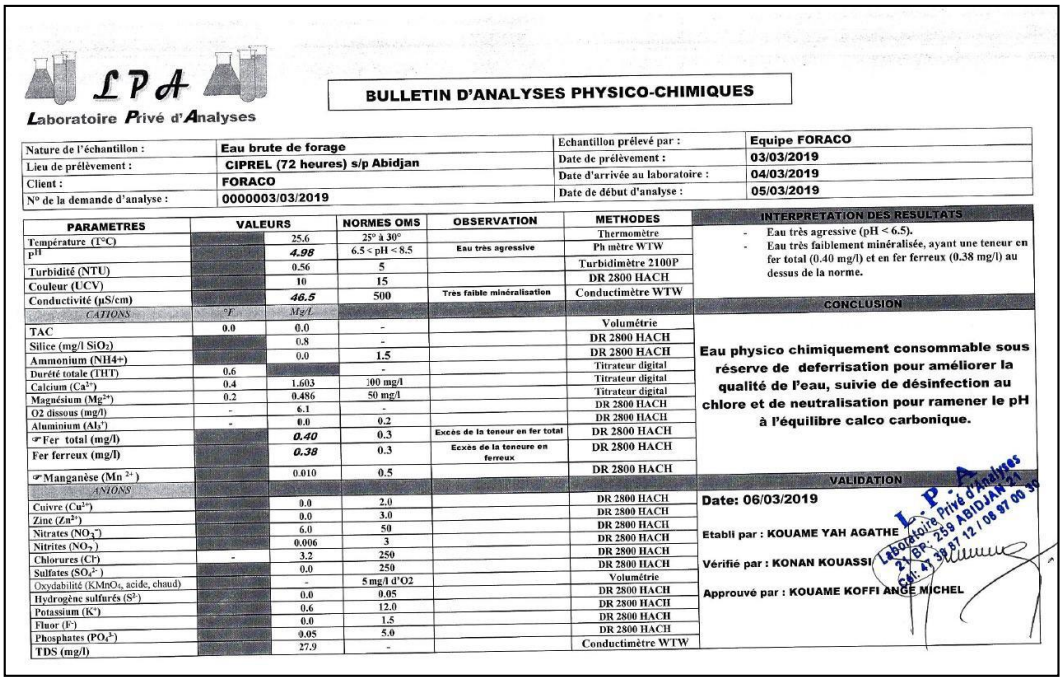
Siège : Abidjan - Adresse postale : 21 BP 259 Abidjan 21 – tél : 08 97 00 30 - RC N° 11461/96 du 20/12/96 - CC: 9705226-Q du 19/02/97 -

Table 3 - Analysis of the drilling water after 72 hours of pumping



LPA
Laboratoire Privé d'Analyses

BULLETIN D'ANALYSES PHYSICO-CHIMIQUES

Nature de l'échantillon :	Eau brute de forage	Echantillon prélevé par :	Equipe FORACO
Lieu de prélèvement :	CIPREL (72 heures) s/p Abidjan	Date de prélèvement :	03/03/2019
Client :	FORACO	Date d'arrivée au laboratoire :	04/03/2019
N° de la demande d'analyse :	0000003/03/2019	Date de début d'analyse :	05/03/2019

PARAMETRES	VALEURS		NORMES OMS	OBSERVATION	METHODES
Température (T°C)		25,6	25° à 30°		Thermomètre
pH		4.98	6.5 < pH < 8.5	Eau très agressive	Ph mètre WTW
Turbidité (NTU)		0.56	5		Turbidimètre 2100P
Couleur (UCV)		10	15		DR 2800 HACH
Conductivité (µS/cm)		46.5	500	Très faible minéralisation	Conductimètre WTW
CATIONS	°F	Mg/l			
TAC	0.0	0.0	-		Volumétrie
Silice (mg/l SiO_2)		0.8	-		DR 2800 HACH
Ammonium ($NH4+$)		0.0	1.5		DR 2800 HACH
Dureté totale (TH°)	0.6		-		Titrateur digital
Calcium (Ca^{2+})	0.4	1.603	300 mg/l		Titrateur digital
Magnésium (Mg^{2+})	0.2	0.486	50 mg/l		Titrateur digital
O2 dissous (mg/l)	-	6.1	-		DR 2800 HACH
Aluminium (Al_3^+)	-	0.0	0.2		DR 2800 HACH
°Fer total (mg/l)		0.40	0.3	Excès de la teneur en fer total	DR 2800 HACH
Fer ferreux (mg/l)		0.38	0.3	Excès de la teneure en ferreux	DR 2800 HACH
°Manganèse (Mn^{2+})		0.010	0.5		DR 2800 HACH
ANIONS					
Cuivre (Cu^{2+})		0.0	2.0		DR 2800 HACH
Zinc (Zn^{2+})		0.0	3.0		DR 2800 HACH
Nitrates (NO_3^-)		6.0	50		DR 2800 HACH
Nitrites (NO_2^-)		0.006	3		DR 2800 HACH
Chlorures (Cl^-)	-	3.2	250		DR 2800 HACH
Sulfates (SO_4^{2-})		0.0	250		DR 2800 HACH
Oxydabilité ($KMnO_4$, acide, chaud)	-	-	5 mg/l d'O2		Volumétrie
Hydrogène sulfuré (S^{2-})		0.0	0.05		DR 2800 HACH
Potassium (K^+)		0.6	12.0		DR 2800 HACH
Fluor (F^-)		0.0	1.5		DR 2800 HACH
Phosphates (PO_4^{3-})		0.05	5.0		DR 2800 HACH
TDS (mg/l)		27.9	-		Conductimètre WTW

INTERPRETATION DES RESULTATS

- Eau très agressive (pH < 6.5).
- Eau très faiblement minéralisée, ayant une teneur en fer total (0.40 mg/l) et en fer ferreux (0.38 mg/l) au dessus de la norme.

CONCLUSION

Eau physico chimiquement consommable sous réserve de deferrisation pour améliorer la qualité de l'eau, suivie de désinfection au chlore et de neutralisation pour ramener le pH à l'équilibre calco carbonique.

VALIDATION

Date: 06/03/2019

Etabli par : KOUAME YAH AGATHE

Vérifié par : KONAN KOUASSI

Approuvé par : KOUAME KOFFI ANGE MICHEL

L.P.A Laboratoire Privé d'Analyses 21 BP : 259 ABIDJAN 21 Cel: 41 39 87 12 / 08 87 00 30

5.6.2. ANALYSIS OF LAGOON WATER

The table below summarizes the results of analyzes carried out on the waters of the lagoon at low tide and at high tide.

The waters of the Ebrié lagoon are brackish with electrical conductivities> 4,500 µS / cm and chloride contents from 173 to 177 mg / L. The mineralization of the waters is 2.4 g / L.

Table 6.5 Qualité de l'eau de la lagune Ebrié au droit de la conduite d'eau (source : ERANOVE, juin 2018)

Paramètre	Unité	Eau lagune (marée basse)	Eau lagune (marée haute)
PH		7,3 à 28,5°C	7,3 à 28,9°C
Température	C°	28,5	28,9
Turbidité	NTU	13,8	18,9
Conductivité électrique	µS/cm	4,7 à 28,8 °C	4,5 à 28,5°C
Chlorure	mgCL/L	173,9	177,3
Salinité	g/L	2,5	2,4
Sulfate	$mgSO_4/L$	134,2	147,1
Bicarbonate	$mgCaCO_3/L$	52	49
TDS	mg/L	2390	2380
Fluorure	mg/L	0,3	0,2
DCO	mgO_2/L	79,1	67,8
DBO	mgO_2/L	30	20
Ammonium	$mgNH_4/L$	< 0,1	< 0,1
Nitrates	$mgNO_3/L$	0,3	0,2
Huiles et graisses	Mg/L	< 0,5	< 0,5

5.6.3. CONCLUSIONS ON THE RESULTS OF WATER ANALYSIS

The analyzes carried out during pumping of the borehole showed that pumping at 90 m3 / h for 72 hours did not attract brackish water from the lagoon. It can be seen that the conductivity values and the chloride contents have remained very stable, which tends to show that the aquifer has a good reserve of fresh water.

pumping ply	pH	Conductivity (ïS)	TDS (mg / L)	Chlorides (mg / L)	Total iron (mg / L)
24 H	5.8	44	26.5	3.2	0.45
48 H	4.4	44	26.4	3.2	0.4
72 M	4.9	46	27.9	3.2	0.4
Lagoon (tide low)	7.3	4700	2390	173	-

6. SURFACE AREA DISCHARGE AROUND THE SITE

The area covered by the pow er plant (delimited by the red dots) is located on a plateau (at present, it is a coconut plantation) w hich slopes gently dow n tow ards the lagoon Drunk from an altitude of + 8 meters NGCI on its southern limit to + 5 meters NGCI at the northern limit of the plot (see Figure 20).

The pow er plant area is bordered by 2 shallow s w ith clay soils (comprising dense forest vegetation) w hich serve as drainage for rainw ater.

Water discharges are observed in these shallow s during heavy rains (C according to information given by local populations) w hile on the plateaus w hose soils are made up of ocher sands, rainw ater flow s little and infiltrates into sandy soils.

The positioning of the thermal pow er plant's catchment area at the level of a flat zone bordered by shallow s w ill facilitate the drainage of rainw ater from the pow er plant tow ards these depressed lateral zones w hich connect to the lagoon (see Figure 20) .

Due to the altitude of the plateau on w hich the pow er plant is built (+ 5 to + 8 m NGCI), the site is not subject to the risk of flooding linked to lagoon w aters.

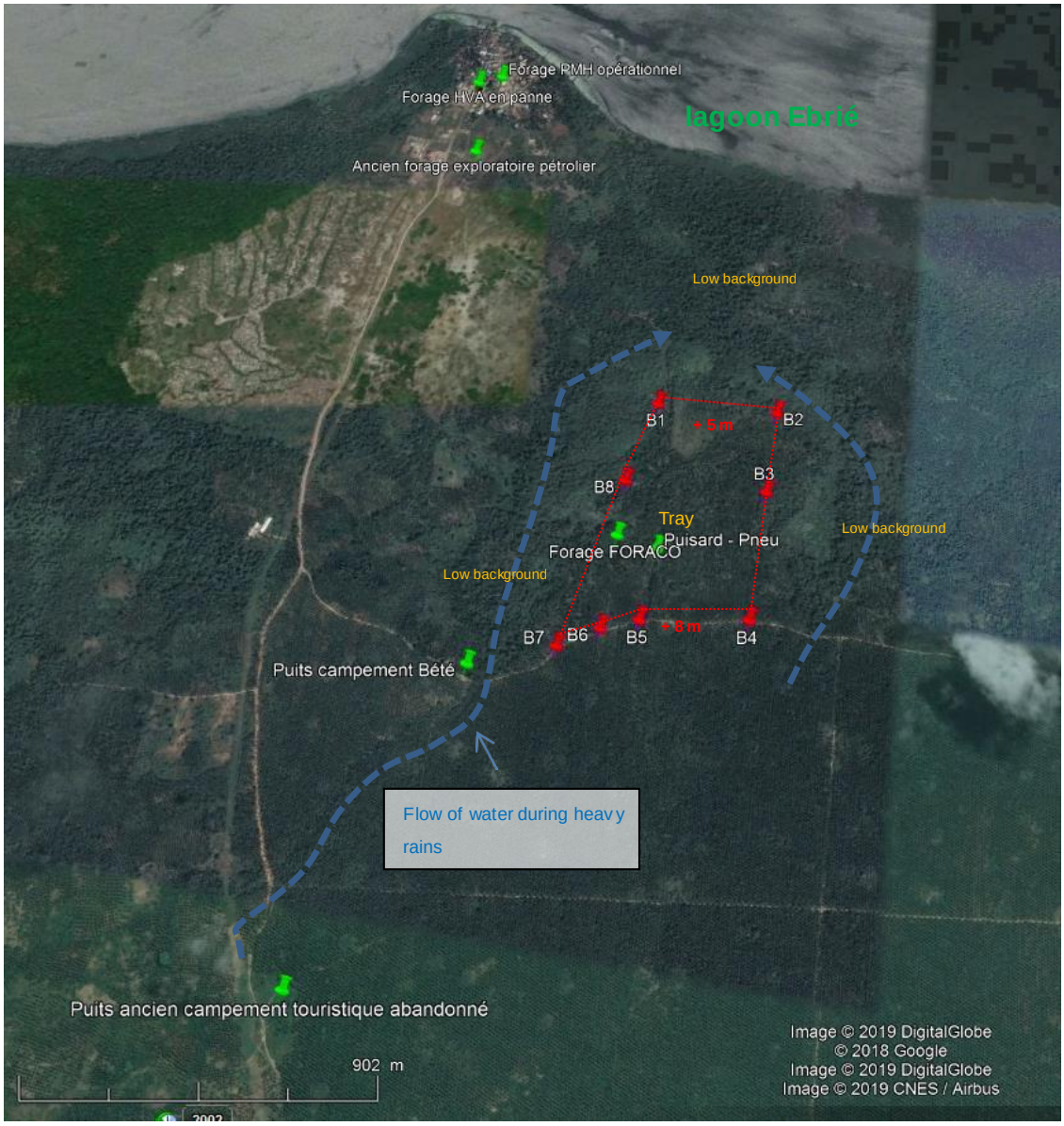


Figure 20 - Morphology of the grip of the central area (HR image Google) and runoff of surface waters in the shallows during rainfall

7. USE OF THE AQUIFER – CURRENT CONDITION

7.1. AQUIFER REQUIRED BY THE PROJECT • THE QUATERNARY AQUIFER

Because of its location, the CIPREL project cannot impact the large aquifers used to supply drinking water to the populations of ABIDJAN and secondary cities; these aquifers as well as the large capturing areas of boreholes are all located north of the Ebrié lagoon.

The aquifer requested by the drilling of the CIPREL 5 power station is the old Quaternary aquifer contained in the sandy formations of the Low plateau of the Taboth sector.

7.2. INVENTORY OF WATER POINTS – CURRENT CONDITION

A census of the Water Points used for the supply of water to local populations (boreholes equipped with human-powered pumps or electric pumps for HVA systems, village wells or simple sumps in the aquifer), and access points at the aquifer carried out as part of the geotechnical or hydrogeological investigations carried out as part of the studies for the CIPREL project, was carried out on April 9, 2019. The different Water Points visited and access points to the aquifer are indicated on the figure 21. They consisted of measurements on the physical characteristics of the water (pH, temperature, electrical conductivity) were carried out when it was possible to take a water sample.

7.2.1. water supply to the village Taboth

The village (2000 inhabitants) is located on the south shore of the lagoon Ebrié, about 1 km north west of the site of the power plant CIPREL 5. It has for the drinking supply of the population:

- An HVA borehole equipped with an electric pump serving a network of standpipes. This drilling would have been carried out in 2018 as part of the PPU (presidential emergency program); it was broken during the April 19 visit (see Photographs of Taboth's HVA systems below).

- An old village hydraulic borehole carried out in 1989 equipped with an ABI type human-powered pump; this drilling is operational and currently constitutes the only water point used by the populations for their consumption. There are wells in the village, the water from these wells is used only for washing.

Measurements were performed on a water sample from the drill:

- Temperature: 32 °
- pH: 6.02
- Electric conductivity: 190 ïS

This is a mineralized water with a higher electrical conductivity (190 ïS) than that measured on the drilling performed by FORACO Site CIPREL (44 ms).

ONEP has been kept informed of the failure of HVA system Taboth.

oil exploration drilling on Taboth	
Note the presence of an old oil research well located near the village. On the geological map this borehole was located with the numbering Tt.1. A cement container was placed around a steel casing (see photo below).	

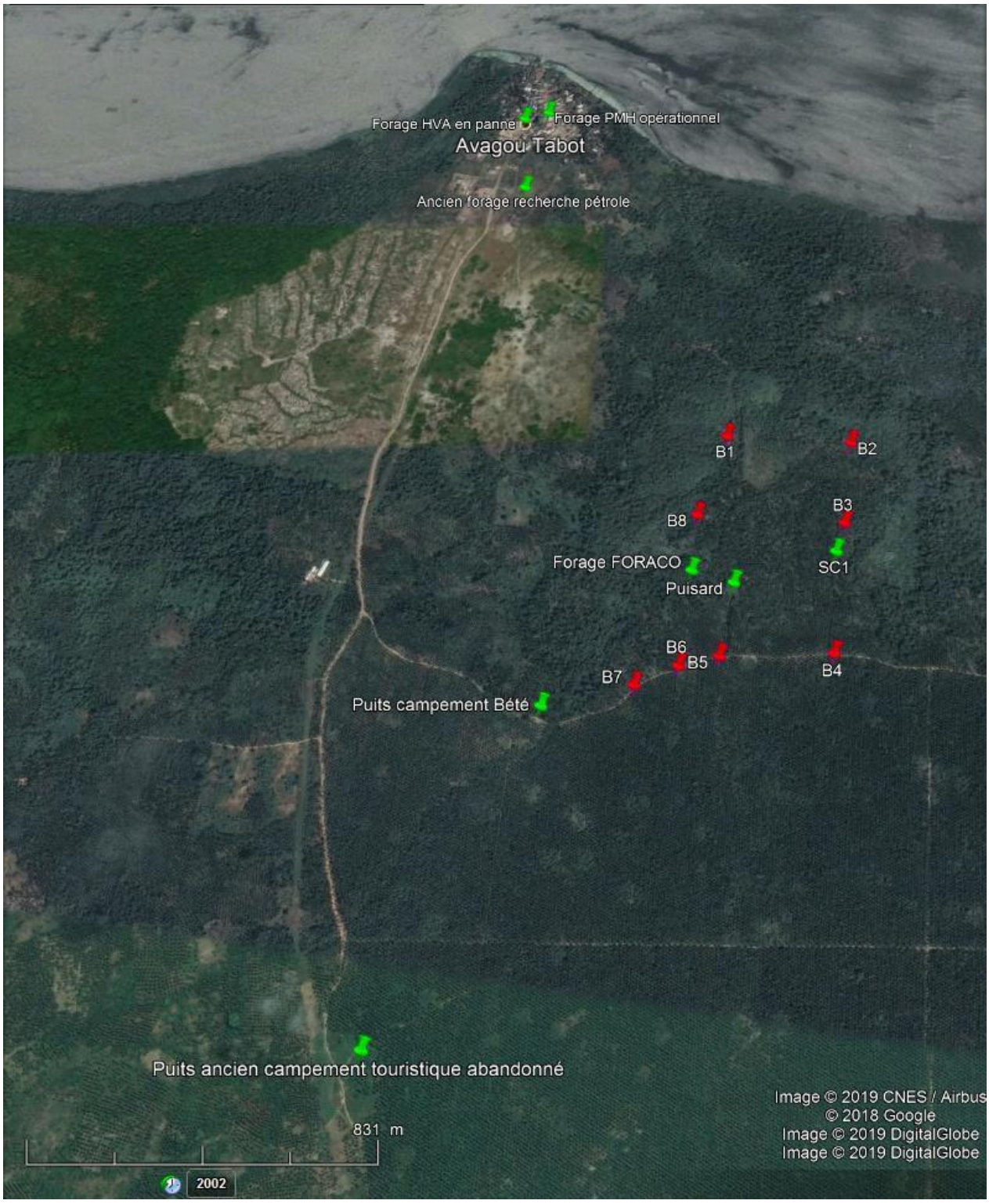


Figure 21 - Identification of Water Point (drilling, boring, well, rain ..)

7.2.2. Well of Camp Bete

Near the CIPREL site (300 meters), there is a small camp, Bété, (a listed dwelling) with a well (see Figure 21). This well was dug near the shallows, it has a coping, however its waters are very colored and must be of poor bacteriological quality given the shallow depth of the well and its lack of protection (open well). The level of the water table is - 1.4 m compared to the NT. The water measurements from this well: temperature 28.4 °, pH 7.18, electrical conductivity: 85 µS.

The consumption of water from this well can, in our view, be dangerous to health if it is not subject to prior disinfection. Also this well is not well-positioned because it is located in a shallow water which drains surface water during heavy rains. This is a book to condemn if people can benefit from a borehole equipped with a human-powered pump or be connected to an HVA system.

7.2.3. Other water points nearby

It was noted the presence of a sump in the aquifer in the middle of the coconut plantation by the CIPREL site; this very basic well (a tire was installed as a coping) is used by the owner of the plantation (Mr. Kokra Koffi François) probably during his work in the coconut grove. The measurements made on the well water: temperature 28.9 °, pH 5.36, electrical conductivity: 10 µS). These are very slightly mineralized aquifers close to those captured by the FORACO drilling (which is located about a hundred meters from the well).

8. CONCLUSIONS & RECOMMENDATIONS

8.1. POTENTIAL RIBBON AND DRILLING

The investigations carried out to date have highlighted the presence of an aquifer in the sandy formations of the old Quaternary under the CIPREL 5 site. Its thickness is around 20 meters; beyond, there are slightly permeable clay formations according to FORACO drilling data. The hydrostatic level of the water table is very close to the NT at the right of the project site: - 0.3 to - 1 m deep under the NT measured on geotechnical surveys and on FORACO drilling. The production of a piezometric map of this aquifer would require the installation of a network of piezometers which does not currently exist. The 2 available groundwater access points (FORACO drilling and SC1 borehole) made it possible to establish a groundwater level at a piezometric level of + 4.5 m NGCI at the CIPREL site, and to show that the flow of the water table is oriented South North towards the Ebrié lagoon.

The sketch of a hydrogeological map proposed in Figure 22 shows the possible extension of the Quaternary aquifer over the Taboth sector at the level of the Lower plateaus (psa), with certain hypotheses on the directions of flow of this aquifer (represented by the red arrows) given the limited data currently available on this sector. The hydrodynamic parameters of the aquifer on the CIPREL site could be evaluated from the FORACO drilling. The transmissivity of the water table is around 5 x 10-3 m2 / s (with a permeability of the sands from 2 to 3 x 10-4 m / s). The good transmissivity of the water table will allow a flow rate of 20 m3 / h to be sampled by drilling with a slight reduction in the level of this water table (approximately 1.2 m at the level of drilling). A second drilling is planned to secure the operation. The 2 boreholes will operate alternately at a flow rate of 20 m3 / h. They will be equipped with flow meters.

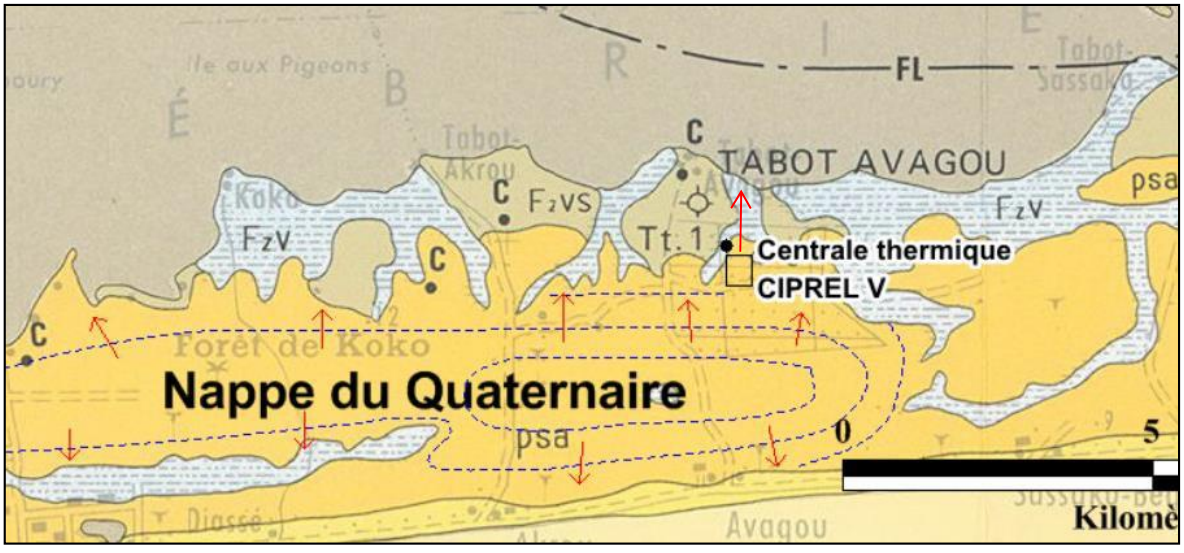


Figure 22 - Possible extension of the water table on Quaternary sector Taboth

The aquifer waters are of very good quality in the area of the CIPREL site. They can be used for the industrial needs of the future power plant, but also as water usable for human consumption (after corrective treatments of pH and iron) and after disinfection.

8.2. ABSENCE OF RISK OF MOBILIZATION OF LAGOON WATERS

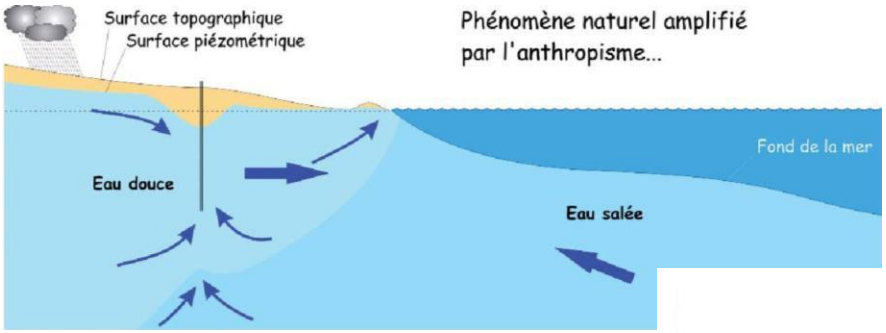
mobilization mechanisms of brackish / salt water in coastal aquifers are explained in Figure 23 below.

RISKS OF MOBILIZING SALT WATER ALONG THE EBRIE LAGOON

Coastal aquifers are more or less sensitive to saline intrusions under natural conditions and under anthropogenic influence depending on their structure, their geometry and the heterogeneity of the environment.

The coastal zone is the meeting point between two types of groundwater::

- freshwater Aquifers continent like **sands of ABIDJAN**
- salt water that permeates the land near the coast or entering waterways in estuaries



The position of the salt water / fresh water is a function of the density ratio of fresh water and salt water. This is why it should be maintained **a hydraulic positive charge of + 2 to 3 m in the body of fresh water on the edges of the lagoon EBRIE to maintain the salt water intrusion depth.**

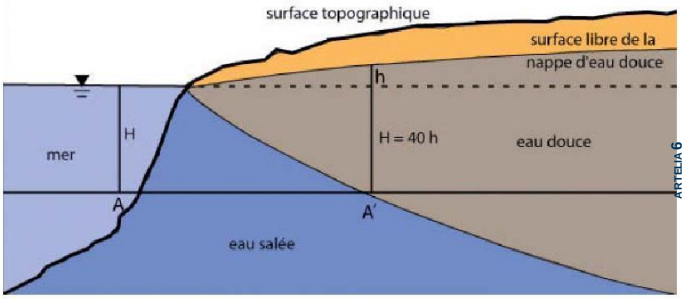


Figure 23 - Mechanisms of mobilization of salt water in

Tests carried out on the borehole have shown that a pumping of 20 m3 / h causes a drawdown of 1.2 m from the level of the water table to the level of the borehole. The dynamic level of the water table will stabilize at a piezometric level which can be estimated at + 3 m NGCI.

With such a positive hydraulic load of the freshwater table (+ 3 m), there can be no mobilization of a bevel of brackish water which would come from the Ebrié lagoon during pumping of the borehole (located at 1 , 3 km from the lagoon) at a flow rate of 20 m3 / h.

8.3. WATER SUPPLY OF VILLAGE Taboth

The boreholes in the village of Taboth will not be impacted by a borehole which will take 20 m3 / h from the CIPREL site, taking into account the distance from the village (> 1 km) and the potential of the water table circulating in quaternary sands.

It was noted that the HVA (improved village hydraulics) drilling in the village of Taboth is no longer functional and no longer supplies the village standpipes connected to the HVA network.
The village has only one borehole for its water supply, fitted with an old ABI-type hand pump.
ONEP services have been informed of the current situation in the village of Taboth.

8.4. Piezometers ON THE SITE OF THE PLANT

It would be useful to create piezometers on the site of the power station in order to measure the seasonal fluctuations of the level of the aquifer. Geotechnical surveys carried out in June 2018 showed that the water table is very close to the ground (- 0.3 to - 1 m / TN).

When the power plant is in operation, these piezometers can be used for monitoring groundwater on the site (checking groundwater levels and monitoring the quality of groundwater).

oOo