University of Victoria – UVIC
Department of Continuing Studies
Restoration of Natural Systems

ER 390 Report: Hydrological Assessment and Restoration of Water Resources in an Aluminum Industry

Student: Davi Teixeira
ID: V00020675
Instructor: Dr Valentin Schaefer

São Luís
2018

ABSTRACT

Fresh water ecosystems certainly perform an extremely important environmental role for the maintenance of biodiversity. The extension of the occupied area is large, therefore, bringing along its environmental impact. Because of this scenario, it is worth stressing the need to comprehend the many aspects responsible for the occurrence of water courses through hydrogeological and hydrological surveys. Through the support of hydrological and hydrogeological field monitoring it was possible to note the water dynamics in a region of 3400 hectares occupied by areas composed of bauxite residue, resulting from the process of generating aluminum. They are called Residue Storage Areas, or, RSA. Surrounding those areas, there are drainage nets mostly composed by springs and streams in which are considered as permanent preservation areas according to the Brazilian Forestry Code. Such areas should remain preserved or immediately restored considering the risks of environmental impact. In most of the cases, earthmoving works have the greatest potential and, indeed, a disturbed area under restoration actions was assessed. Basic restoration recommendations were set in the end with special attention in the implantation of drainage controlling devices.

CONTENT LIST

SUMMARY

1) INTRODUCTION

São Luis Island in the coastal plain of Maranhão state (2° 31′ 42″ S, 44° 18′ 16″ W). There are four counties in the Island called: “Paço do Lumiar”, “São José de Ribamar”, “Raposa” and São Luís, where the capital of the state is located (Image 1). Also, circling the island there are 3 important bays called Arraial, Sao Jose and Sao Marcus which separate Sao Luis from the Mainland.

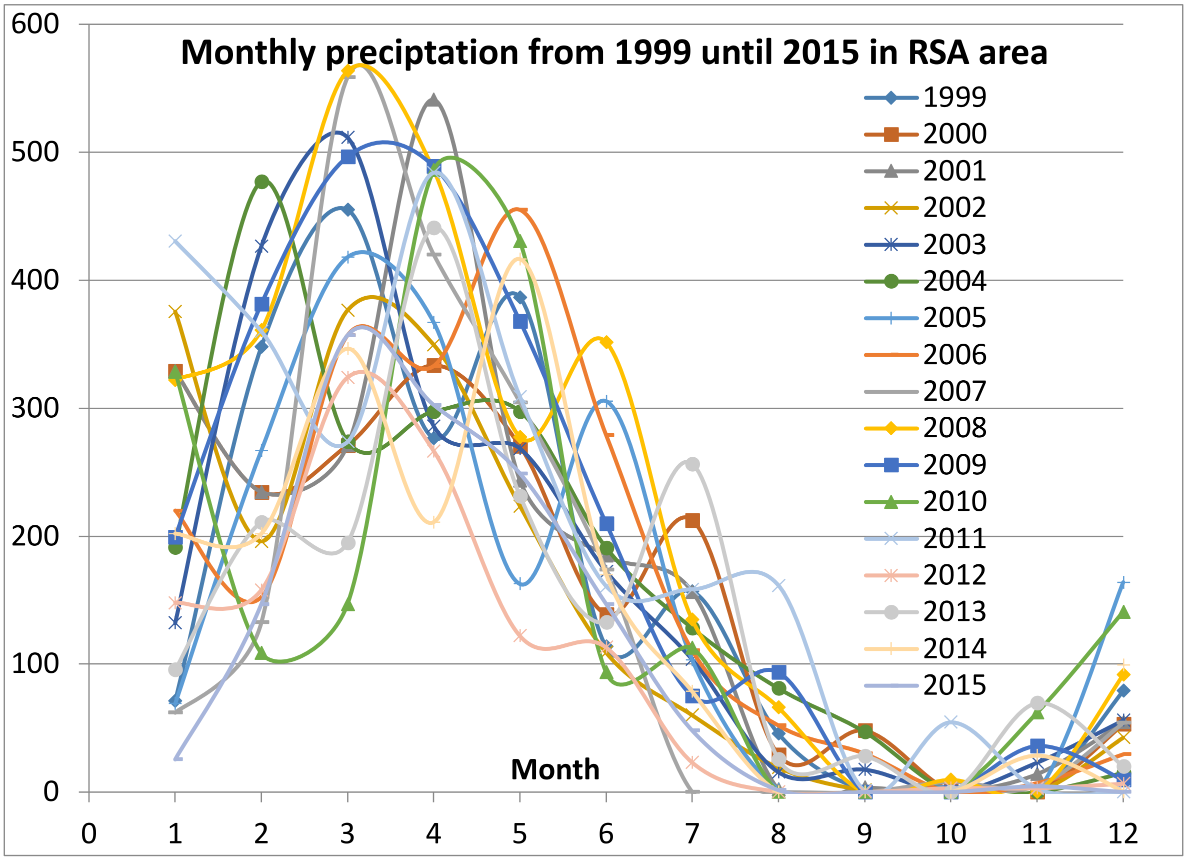
At the south of the Island is located a major Aluminum industry that occupies an area where occurs three types of ecosystems in general: mangrove at the west part, where the port facility was built to receive the main raw material bauxite, dry land with secondary growth bush and a great number of scattered water courses. These systems to the north and east make up a buffer zone of approximately 3,400 hectares. To the east there are artificial lakes for the disposal of bauxite residue called Residue Storage Areas - RSA´s (Figure 1).

Image 1: RSA area

Source: Google EARTH, 2017

During RSA construction period, it is very important to adopt mechanisms that can protect the surrounding native vegetation, during heavy rainfall period (from February until May with rain peak in March – Graphic 1).

Because of this high rain regime this area is considered the largest aquifer recharge area in Island of São Luís.



Graphic 1. Background precipitation.

As a consequence, there are a significant number freshwater ecosystem, mostly composed by springs (water table outcrop areas) and streams nearby the RSAs.

Concerning the general vegetation components, there is a great diversity of indicator wet species from the *Arecaceae* family such as *Euterpe edulis, Euterpe oleraceae*, *Mauritia flexulosa* and *Calophyllum brasiliense Cambess* which are common and are an excellent food resource for the local community nearby.

The community of “Pedrinhas” (in English means “little stone”) with a population size in approximate 2,500 is a major village that surrounds the whole industry, it has been there for several generations before the industry was installed and, thus, is crucial to obtain a good dialogue, due to the constant demand for new operation areas to build new bauxite residue disposal areas.

Above all, the Brazilian forestry code of 2012 classifies fresh water ecosystems as protected areas with the crucial role of protecting hydrological resources and biodiversity. Therefore, they must be protected. The only exceptions accepted for a project that may impact on these areas are for research, ecotourism and environmental education, obviously not including industrial enterprises (Article number 3, item 2 and 5). And still it´s need to be signed off by the state governor.

Considering the context above, the characterization of those particular areas will focus at first on the hydrogeological/hydrological basic study. Second, map design concerning the legal limits of the water courses. Finally, restoration recommendations will be assessed for the disturbed areas where intervention is cleared needed.

2) PROJECT SCHEDULE

The project schedule is presented in Table 1 below.

1) HYDROGEOLOGICAL STUDY		
ACTIVITIES CARRIED OUT	**START**	**END**
Mobilization of the drilling team	06/03/2017	06/03/2017
Location of the drilling points	07/03/2017	23/06/2017
Drilling execution	13/03/2017	29/06/2017
Monitoring wells instalation	20/03/2017	30/06/2017
Desmobilization of the team	30/06/2017	30/06/2017

Water table flactuations reading	05/09/2017	09/02/2018
2) HYDROLOGICAL STUDY		
ACTIVITIES CARRIED OUT	**START**	**END**
Water quality analyses	20/03/2017	20/12/2017
Ploviometry recording	01/01/2017	31/12/2017
Stream flow measurement	05/09/2017	14/02/2018
3) TERRESTRIAL WATER BODIES MAPPING		
ACTIVITIES CARRIED OUT	**START**	**END**
Topography survey	15/08/2017	15/10/2017
Data compilation	15/08/2017	15/10/2017
Map elaboration	15/08/2017	15/10/2017
4) RESTORATION CONTEXT		
Evaluation of areas impacted areas	Throughout the year	
Identification and characterization of the impact	Throughout the year	
Control actions	Throughout the year	
5) RESULTS AND DISCUSSIONS		

Ground water monitoring	20/01/2018	20/02/2018
Stream flow monitoring	20/01/2018	20/02/2018
Pluviometry monitoring	20/01/2018	20/02/2018
Water quality analysis	20/01/2018	20/02/2018
Map elaboration	20/01/2018	20/02/2018

3) MATERIALS AND METHODOLOGY

3.1) MATERIALS:

- Basic components for the design of the 70 wells: Pre-Filter, Bentonite, Geomachanic smooth tube 2", Geomechanic filter 2 ", embankment, protection slab, well top cap and well bottom cap, rope and tripod (Giampá and Gonçales, 2013).
- Field Notebook;
- RTK GPS
- Software Google Earth 2017
- 2 rain gauges;
- Gloves/ bottles;
- Safety Individual Equipment: Long sleeve shirt, boots, helmet, safety glasses, insect repellent, raincoat.
- 1 water level measuring;
- 1 bottle of water
- Measuring tape
- 1 fluviometric ruler

3.2) **METHODOLOGY**

3.2.1) IMPLANTATION OF HYDROGEOLOGICAL MONITORING NETWORK

A hydrogeological survey was first carried out in order to obtain monthly results concerning water table fluctuations from September 2017 to February 2018. The choice of drilling points addressed the location of the same next drainage areas and some points in the higher parts to obtain the maximum level of water level in dry period.

This study was important to understand water table fluctuations regime, responsible for the occurrence of the local springs and stream. So that it is a crucial activity in terms of assessing water availability both in surficial and sub surficial system. As final product, it will be generated water level data from September 2017 to January 2018 – dry period.

The first wells were set in early April, based on technical knowledge of drilling execution by specialist Geologist who established the location of the drilling points with support of local expert who provided the coordinates of all the 69 wells across the 3.400 hectares site (Image 2) Safety equipment was utilized to perform the trails, as the company safety procedures.

Image 2. Monitoring wells locations

Source: Google EARTH, 2007

Basically, the construction of the monitoring wells is carried out as follows:

• Auger drilling (picture 1) at 6 "diameter until the water level is reached;

• In another step, coat the well with steel tubes and continue the drilling with valves tubes, at enough depth to locate the top of the filter 2 m below the static level;

• Coating column composed by geomechanical PVC filters with a 0.5 m groove and a 2 "geomechanical PVC smooth tube. Install centralizers next to the base and top of the filter;

• In the 6"/ 2" ring space, place a pre-filter with a diameter of 1.2 to 2.4 mm, as far as possible, 3 m above the filter, where 1 m of bentonite is poured, after filling with soil up to 1 m below the floor to receive cementation. The 2" pipe extends 0.9 m above the ground, being closed with padlock and cover;

• Cleaning is performed by a piston pump, until water comes out with low turbidity;

• Finishing is made by wrapping the 2" column by cementation, in cylindrical form at 10" diameter, having at its upper end, metal cover, fastened by inlaid and screw with yale wrench.

While the first wells were being located, the drilling activity was taken place in parallel, to optimize time. In total, 3 teams of 5 employees took over the drilling activities, coordinated by 1 foreman, under technical orientations, as picture 1 below.

As final product, it will be generated water level data from September 2017 to February 2018.

Picture 1. Auger drilling

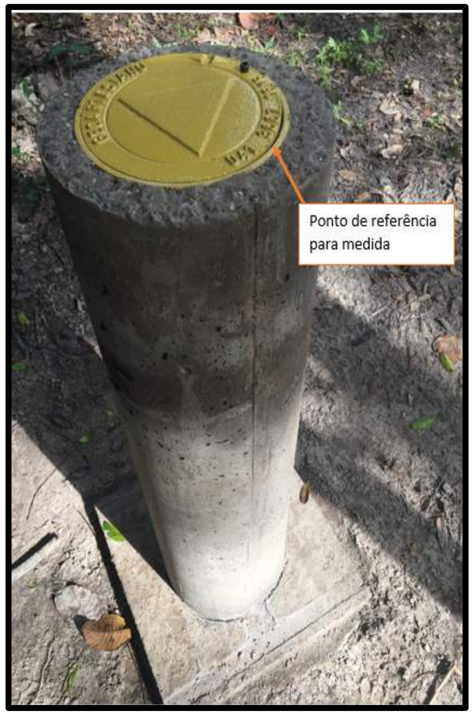
The complete implantation of the monitoring wells was finished in August / 2017 and the water level measures campaign was initiated in September 2017.

As the water table fluctuation reading is performed manually, without prejudice to the definition of the seasonal variation, the time interval of one month between the readings was adopted.

The readings were done with the support of equipment water level measuring (picture 2) with electric sensor, flat double cable with steel core and with centimetric marking. To get to the monitoring wells it was necessary to use a tracked? vehicle and a field GPS, by the support of a contractor company in which was trained in how to use the water level measuring before the beginning of the campaign.

Picture 2: Water level measuring

As a reference for the measurements, the inner part of the ring of the metal cover is used as indicated in the photo below.



Picture 3: Monitoring well

The graphics in Appendix 1 have in the abscissa the number of days between the reading date and February 2017.

3.2.2) IMPLANTATION OF HYDROLOGICAL MONITORING NETWORK

3.2.2.1) *PLUVIOMETRY AND STREAM FLOW MEASUREMENT*

In parallel to the installation of the piezometers, monitoring of hydrological parameters were carried out approaching firstly rainfall data collection through 2 rain gauges installed in early 2017 for acquisition of data including wet and dry seasons from January 2017 until December 2017. The points regard to the area of the field office (1) and main office (2) since image below:

Image 3: Rain data collection points

Source: Google Earth, 2017

These devices of easy utilization could attend with no discrepant data, so that the distance between the points was just 1.15 Km thus it was normal to have small variations and, overall, the rain gauge in point 2 have registered a higher water column (mm) compared to point 1 throughout the project time line.

The readings were made by the security officers with daily visits to the points (Figure 7), so called administrative containers area and field containers. Manual recording and precipitation data report to EHS staff was also included in the demand chronogram of the security officers.

Second, water courses stream flow monitoring was carried out aiming to correlate the precipitation occurrence to the seasonal stream flow, as the rains feed the natural water reservoirs and consequentially increase the flow volume in streams.

A total of 8 points were selected where there is a greater water contribution of upstream water courses, through field visits in June 2017 and collection of geographical coordinates, so that the points could be represented in Google Earth 2017.

The pictures below show 3 of the total points by September 2017, since they are in areas where there is a significant water contribution from upstream water courses regardless the type of the period (dry or wet) and, so that the water availability is supported by water table out crop which forms scattered springs around the RSAs area.

The points are in the following water courses described in Table 2 below with their coordinates:

STREAM FLOW MEASURING POINTS		
SURFECE BODIES	COORDINATES	
	SOUTH	WEST
Igarapé Pedrinhas	2º42´14.71”	44º18´25,76
Lagoa da Babilônia	2º44´09.79”	44º18´6,58
Igarapé Anajatiua	2º42´28.88”	44º16´31,43
Igarapé Brejo Grande	2º43´2.58”	44º17´47,12
Igarapé Brejo Grande II	2º44´9.64”	44º17´30,89
Igarapé Aracauá	2º43´47.95”	44º16´33,77
Igarapé Porto Aracauá	2º44´12.66”	44º17´9,51
Igarapé Aracauá 2	2º44´5.54”	44º16´38,82

Table 2: Stream flow measuring points

The name *igarapé* is an indigenous denomination of Maranhao state to indicate the occurrence of a small creek.

Below are some pictures that represent 3 stream flow measuring points. They were taken in September 2017.

Picture 4: *Aracaua*

Picture 5: *Pedrinhas*

Picture 6: *Brejo Grande*

The location of all the 8 sections in Google Earth 2017 map is represented in the image below.

Image 4: Stream flow measuring points

Source: Google EARTH, 2017

The method used to measure the flows was that of the floating method, due to the characteristics of water bodies with low velocity in the water course. A 600ml plastic bottle was used as standard float and field methodological procedure were followed as per below consulting recommendations for stream flow measurements:

• Choose a location that the course is rectilinear, for four to six meters length;

• Prepare the stream bed so that it can have satisfactory dimensions;

• Measure section of stream bed (width and depth) in at least three points;

• Site demarcation with of concrete foundation;

• Measure the distance between the starting point and the end point, duly defined;

• Measure float velocity time at least 3 times;

• The velocity used to calculate the flow will be the average velocity measured with the empty float and velocity with the float filled at one third of its volume.

The materials utilized to carry out the measurements are described below with photographic record in the end of this section:

• Empty plastic bottle of 600ml in the first step and in a second step the same bottle with one third of water;

• Fluviometric meter for depth measurement at the 3 points fixed of the gutter;

• Tread for measuring the widths at the 3 points of the gutter;

• Timer to determine float travel time between start and end points

Once in the field, it was set a 6 meters length cross section and 5 subsections within it. So the 5 subsections had their respective depths measured by a fluviometric ruler as well as their width (measuring tape). In the end a plastic bottle filled with water at one third of its total volume was utilized to measure the total time spent by the float to run the cross-section length. Some of the sections are shown in the pictures below. This method requires a minimum of 3 repetitions to measure time (PALHARES et al 2007).

The results of the stream flow monitoring are presented through illustrative graphic representing the relationship of water courses stream flow x precipitation occurrence.

Picture 7: Section demarcation

Picture 8: Section demarcation

Picture 9: Float utilized

3.2.2.2) *WATER QUALITY ANALYSES*

In parallel to the hydrological/hydrogeological study, water quality analysis was carried out in water courses. The water course chosen for the sampling was the stream locally called as “Brejo Grande”, as it is located very close to the RSA 6 construction and certainly there are risks of sediments wash off from earth moving activities in the rainy season.

So that the sampling occurred in wet and dry peaks of the year (late March and early October), aiming to contrast the results among environmental parameters of great concern for earthmoving big projects. The parameters approached were turbidity, dissolved oxygen, temperature, pH and total dissolved particles. Materials utilized for water analyses were gloves, turbidity meter, glass bottle, thermometer, portable pH measuring and an Imhoff cone.

Finally, the CONAMA 357 (Brazilian Environment National Counsel) was consulted to verify if the water parameters were in accordance to the Counsel legal standard.

3.2.4) TERRESTRIALWATER BODIES MAPPING

Terrestrial water bodies mapping was accomplished through the support of topography service coordinated by specialized consulting. This service was required since there are a significant number of water courses, lakes, swamp forests and mangroves surrounding the industry.

Those ecosystems are classified as permanent preservation areas according to the Brazilian forestry code and should not be drained for industrial purposes.

So, this service has consisted at first on the preliminary from the observation of possible drainage routes indicating freshwater/wet land environment. This stage was carried out in the administrative office with the support of Google Earth 2017. In addition, supportive map presenting the existing drainage net of the industry and micro basins location was provided by the environmental department.

Once in field, at first it was adopted the biological factor - wet species indicators (picture 10) below) which demonstrate the occurrence of a water course or parched water table in that environment and, since preliminary observation, it was confirmed water courses ecosystems as the majority identified with springs and streams.

The coordinates were obtained in field with a RTK GPS and storage in Google Earth 2017 data base (SHP file) as well as Autocad (DWG file) to support the map elaboration in parallel.

Afterwards the field team measured the width of the whole stream bed (physical indicator) with measuring tape and then it was marked the right and left margins of the stream with zebra ribbon. Such factors are important in SWOT analyses (ER 327 Module 2: Fresh water/wet land ecosystems).

From the acquisition of each stream width, it was determined the legal protection distance of each water course surveyed.

The coordinates were obtained in field with a RTK GPS and storage in Google Earth 2017 data base (SHP file) as well as Autocad (DWG file).

Picture 10: Wet species indicator plants with common name

Bastão do imperador

Guarimã

Juçara

Samambaia do brejo

Miconia sp

Bananeira do brejo

Guanandi

Buriti

The next step approached the Federal law 12 651/12 – Brazilian Forestry Code as the legal literature support, representing the federal sphere as the main guideline for legal limits establishment. Below are listed the specific protection distance according to the dimension of the ecosystem and what ecosystems are considered as a permanent reservation are according to the Federal law – the extension strip to be protected should consider from the edge of the margin of the surficial water body:

A) The marginal strips of any natural and intermittent natural watercourse, excluding ephemerals, from the edge of the stream bed, should adopt the following protection distance:
- 30 (thirty) meters for water courses of less than 10 (ten) meters wide;
- 50 (fifty) meters, for water courses that are between 10 (ten) and 50 (fifty) meters wide;
- 100 (one hundred) meters for water courses ranging from 50 (fifty) to 200 (two hundred) meters wide;
- 200 (two hundred) meters, for water courses ranging from 200 (two hundred) to 600 (six hundred) meters wide;
- 500 (five hundred) meters, for water courses with a width exceeding 600 (six hundred) meters;

B) The areas around lakes and natural lagoons, will be adopting the protection distance of:
- 100 (one hundred) meters in rural areas, except for a water body with a surface area of up to 20 (twenty) hectares, whose marginal range shall be 50 (fifty) meters;
- 30 (thirty) meters in urban areas;

C) The areas around the springs and the perennial water eyes, whatever their topographical situation, within a minimum radius of 50 (fifty) meters.

D) Slopes or parts of slopes with declivity greater than 45 °, equivalent to 100% (one hundred percent) in the line of greatest slope

E) Sandbanks as dune fixers or stabilizers of mangroves.

F) Mangroves in all their extension.

G) The edges of the tablelands, up to the line of rupture of the relief, in a strip never less than 100 (hundred) meters in horizontal projections.

H) Swamp forests with marginal band, in horizontal projection, and a minimum width of 50 (fifty) meters, from the permanently swampy and waterlogged space.

Such strips of land are designed to protect soils and especially riparian forests, which serve to protect springs, stream/rivers, lakes, mangroves etc against potential impacts, ensuring the supply of groundwater and maintenance of freshwater/wet land biodiversity.

In the context above the areas approached are included in the following items:

Second line of item A - marginal strips around water courses. It was adopted 50 m as protection distance, once there was no water course in the whole industrial property ranging more than 50 m. Instead there are a significant number of scattered springs distributed throughout the RSA area due to the seasonal water table fluctuations. So, the item C automatically is considered as well – marginal strips around springs and protection distance of 50 m.

Also, the item B is taken into consideration; there were found 2 dammed artificial lakes with less than 5 hectares, eventually its marginal land need to be protected.

Mangroves widely dispersed in the west part of the RSA area were considered as protected areas in their entire extension (Item C). Finally swamp forests ecosystems located in the north and east part certainly had their marginal strip protected by the support of the topography field team.

Therefore, the field survey has counted with 5 different types of ecosystem: Streams/springs, lakes, mangroves and swamp forests.

The Google Earth map, shows the contour of the permanent preservation areas and local micro basins (catchment). Legends and arrows were utilized to make the identification possible.

In the map the boundaries of the ecosystems are delimited, as well as the line that limits the requirement of preservation of the margins as a limit of the protected areas according to each situation, that is, spring or stream margin.

However, Autocad map could not be imported to Microsoft word platform due to its incompatible format, being accessible only in physical format.

Those maps are an evidence of the correct land management from which big industries should adopt in terms of ecosystems protection, representing the drainage net of the local freshwater/wet land ecosystems along with the micro basins delimitation under the legal recommendation.

Taking into consideration the constant operation demand for future RSA areas, certainly this service has demonstrated to be extremely important, since those ecosystems must not be drained under any circumstance.

3.2.5) **RESTORATION RECOMMENDATIONS**

Restoration recommendations could be set at first through identification of disturbed areas by field visiting, coordinates collection with GPS and further visualization in Google Earth 2017 aiming to determine the extension of the impact. Obviously photographic register was done.

Environmental impacts in terrestrial water bodies resulting from unprotected slopes are used to being one of the biggest threats for the health of the water courses and local biodiversity.

This particular activity is crucial for the follow up of the environmental inspections chronogram of the RSAs area, as the projects must operate with the lowest environmental impact.

Second, it was carried out proper identification of the cause which may have contributed for the environmental impact. So that inspection of the sediments controlling devices was carried out which includes geotextile, drainage levees, gully, sediments storage area and drainage path.

Critical analysis of the water parameters which regulate the environmental functions of swamp forests was done since the section *water quality analyses*. The legislation utilized was CONAMA (Environmental National Council) 356.

Finally, short term actions, medium term actions and long-term actions were established based upon the cause of the environmental impact.

4) **RESULTS AND DISCUSSIONS**

4.1) IMPLANTATION OF HYDROGEOLOGICAL MONITORING NETWORK

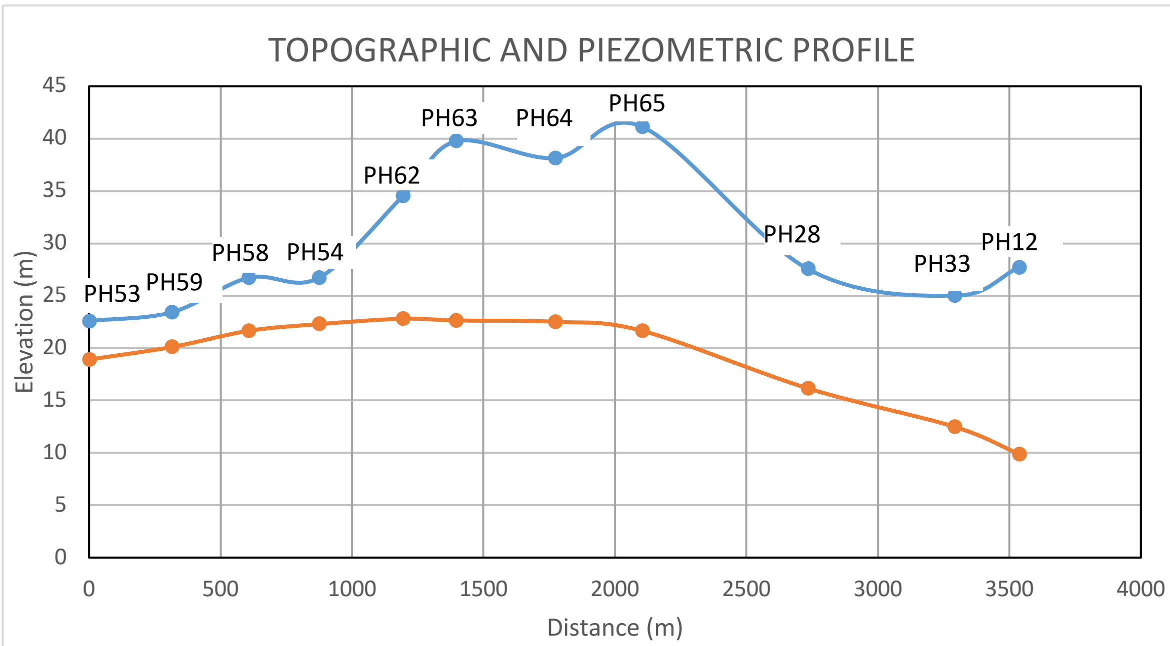
At first, it was verified an increase in ground water level due to the topographic level variation, so that the local topography follows the water level. The relationship water level x topography variation is presented in the image (yellow line reference), table and graphic below, indicates the behavior of the water level in the monitoring wells from PH 53 to PH 12, as an example of these aspects.

Image 5: PH 53 to PH 12

Source: Google Earth, 2017

Monitoring well	P53	P59	P58	P54	P62	P63	P64	P65	P28	P33	P12
Distance	0	315	608	874	1193	1397	1773	2104	2734	3290	3537
Height (m)	22,59	23,43	26,73	26,71	34,52	39,75	38,14	41,11	27,54	25,01	27,71
Water level	18,91	20,11	21,66	22,29	22,81	22,64	22,51	21,64	16,15	12,50	9,88

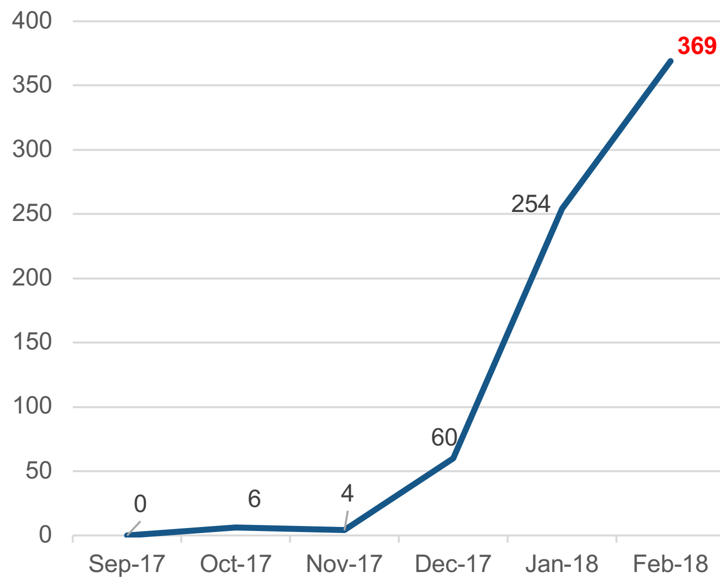
Table 3. Water level behavior



Graphic2: Topography x Piezometry

The local topography follows the elevation so that higher elevations, overall, means a higher water level in the groundwater system.

Second, it was note variation in water level from September 2017 to February 2018 due to the abrupt increasing of rain presented in the graphic below, presenting



Graphic 3: Rainfall (mm)

Also, the results in Appendix 1 present slight decreases for mostly of the monitoring wells, which is an extremely important factor indicating a very strong hydrogeological system capable in storing a significant water volume regardless the seasonal period in question. In this case it was decided to present the behavior of the levels in period of change of season from the driest month to the first rainy months.

Therefore, the ground water system can maintain a significant flow volume to feed springs and streams, definitely resilient ecosystems for the long-term perpetuation of aquatic/terrestrial species.

4.2) IMPLANTATION OF HYDROLOGICAL MONITORING NETWORK

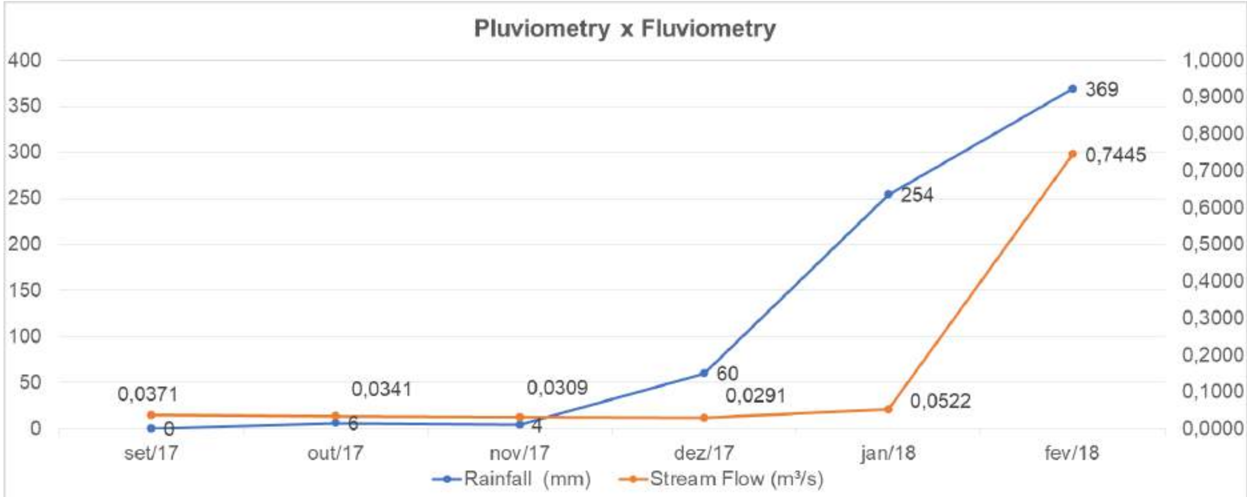
From September 2017 to January 2018 it was possible to carry out the stream flow measure only in Pedrinhas stream, being the only water body where runoff is perennial in every month during the dry season. The rest of the water bodies had not shown a propitious scenario for the execution of the activity from September 2017 to January 2017 because of the factors: absence of water flow, absence of defined stream bed through the whole stretch of the stream and absence of rain. The table below exemplifies this scenario:

Water Body	set/17	out/17	nov/17	dez/17	jan/18	fev/18
Pedrinhas (m^3/s)	0,0371	0,0341	0,0309	0,0291	0,0522	0,7445
Babilonia (m^3/s)	dry	dry	dry	dry	dry	0,0519
Brejo Grande 1 (m^3/s)	no flow	no flow	no flow	dry	no flow	0,2259
Brejo Grande 2 (m^3/s)	Dry	Dry	Dry	Dry	Dry	no flow
Anajatiua (m^3/s)	no flow	no flow	no flow	no flow	no flow	no flow
Porto Aracaua (m^3/s)	dry	dry	dry	dry	dry	0,0050
Aracaua (m^3/s)	0,0096	no water flow	dry	dry	no flow	0,3006
Aracaua 2 (m^3/s)	no flow	no flow	no flow	no flow	no flow	no flow

Table 4. Stream flow values

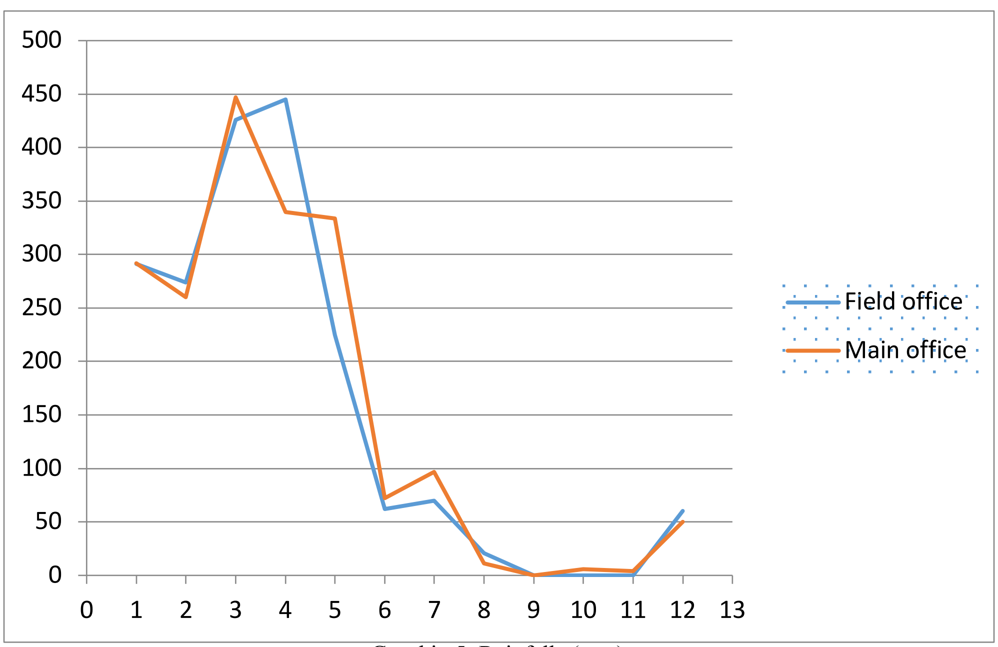
Despite some water bodies remained dry, such trend has proofed to be short. Certainly, from February and on the water availability will significantly increase, contrasting a lot with the dry period.

Concerning Pedrinhas, the floating methodology adopted and the collected pluviometry data indicated the graphic below, where it was certainly possible to observe an increase of the values throughout the months of field monitoring with rainfalls. It is clearly shown the abrupt change considering the dry months and January/February with the beginning of rainfalls.



Graphic 4: Pluviometry x fluviometry

The occurrence of rainfalls throughout the year (graphic below) have demonstrated to have a great influence in the recharge of ground water system and water courses feeding, so that only 3 water courses remained dry for a short period in 2017 and 3 remained with no flow /standing water. The data were collected in the last day of each month being reported by the 2 security inspectors from the main/field offices.



Graphic 5: Rainfalls (mm)

Hence, both hydrogeological and hydrological data have demonstrated the very important role of the physical environment in providing freshwater/wetland habitat for the local biodiversity and certainly for the surrounded human communities.

4.2.2) WATER QUALITY ANALYSES

Water quality analysis results were assessed right after sampling methods in field through the support of a basic equipment suitcase containing the cited materials

Table 5 below presents the data from the sampling and analyses on 25/03/2017 and 20/12/2018.

WATER QUALITY RESULTS IN BREJO GRANDE STREAM			
PARAMETERS	**VALUES (mg/l)**	**COLLECTION PERIOD**	**LEGAL LIMIT**
Turbity	> 1100	25.03.17	40 NTU
	100	20.12.18	
Temperature	27	25.03.17	40°C <
	30	20.12.18	
Dissolved Oxygen	0	25.03.17	> 6mg/l
	2	20.12.18	
pH	6,3	25.03.17	6.0 - 9.0
	6	20.12.18	

Table 5. Water quality results

According to the values above the stream has been severally disturbed and the cause was sediments accumulation in the stream bed/silting by heavy rain event impacting in non-revegetated slopes at the external east dike area of RSA 6 (more detailed in the result section of restoration recommendations).

The extremely high values of turbidity (suspended particle matter) reflect in a very low rate of dissolved oxygen. Also, eventually with the first deaths of the most sensitive tree species, temperature will trend to increase due to the lack of shade provided by broadleaf species such as the *Euterpe oleracea* and Calophyllum brasiliense – highest number of dead individuals according to field verifiers

On 20/12/2018 there was a significant improvement in those values specially turbidity and dissolved oxygen in some rehabilitated wet areas (see pictures in restoration recommendations section) due to the occurrences of small channels and pounds formed as result of the first rains in December 2017 and especially environmental controlling measures executed throughout the year (restoration recommendation section).

It is expected that dissolved oxygen increases with the beginning of rains by February 2018 with the rain wash and sediments drainage towards Arraiao's bay, allowing a greater water flow.

4.3) TERRESTRIAL WATER BODIES MAPPING

Image 6 below identifies the occurrence of the ecosystems within its protected area limits. Arrows of different colours indicate each ecosystem's location: purple arrow - swamp forest, green arrow - mangrove, blue arrow - natural and artificial lakes and red arrow - occupation area (small pig farming). The red line surrounding the RSA area represents the property limit established for the plant in accordance to the State Decree 7646 from 1980 in which has created the SLID (Sao Luis Industrial District).

Image 6: Map of terrestrial water bodies

Source: Google Earth, 2017

Springs and streams are inserted within the green contour represented by the permanent preservation area strip. The round shape corresponds to the spring location with a ratio of 50 m as extension strip to be protected and the parallels line (cannot be seen) corresponds to the water course/stream surficial drainage, adopting the same protection distance of 50m.

It was observed during the field diagnosis, which can be observed in the map of the area, that the microbasins of *Anajatiua*, *Aracaua* and *Brejo Grande* have their extension located within the limits of the property of the plant, being its mouth located in the mangroves from *Arraiao* bay. The micro basin of Babylon, despite being a contributor to the Bay of *Arraiao*, has its mouth beyond the limits of the plant's property. The micro basin of *Pedrinhas* also has its mouth out of the property boundaries, advancing towards BR-135 highway.

However, in the Pedrinhas micro basin, specifically in Pedrinhas stream, there is a strong disturbance of the spring, resulting from the silting process by the deposition of sediments from the construction of RSA 5 in 2013, since the sediments controlling device (sedimentation basin). The silting covers beyond the area of the spring, reaching part of the main stream bed.

Still in this microbasin, at the karoko stream, the contour of the permanent preservation area limit including the two margins does not maintain native vegetation within the required limits, presenting areas with the presence of invasive grass (ginger grass), resulting from the use of these areas for exploration in the cultivation of vegetables that occurred several decades ago by former residents.

In the past former residents produced vegetables crops as livelihoods. The areas used for production were usually located near streams to facilitate the abstraction of water for irrigation of crops.

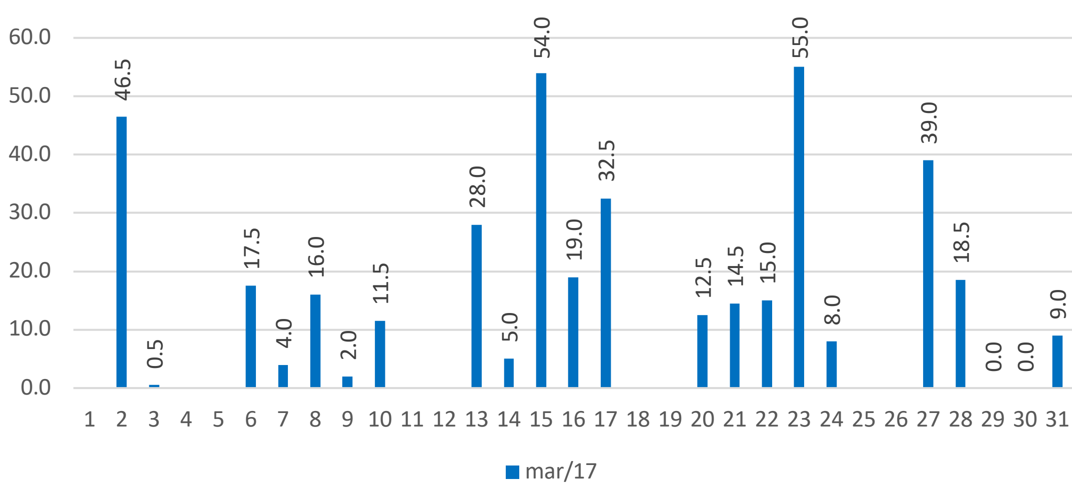
4.4) RESTORATION RECOMMENDATIONS

In the external east part of RSA 6 it was identified an event of environmental impact caused by rain in April 2017, right after the water collection/sampling in March 2017.

As a result of the strong rainfall occurred on March 15 2017, the overtopping of the sedimentation basin number 03 (Picture 11) caused by a sediments wash off in a slope unprotected area from the Residue Storage Area 06 has occurred, causing the silting of the stream the Brejo Grande within a protected area.

Picture 11. Overtopping event

On that day alone it rained more than 50 mm in 60 minutes which has caused the event above. Figure 17 below represents the precipitation of March as the wettest month in 2017 with 400mm.



Graphic 6: March Daily precipitation

The overall environmental impacts are listed in below. Picture 12 represent the visual impact

- Aggravation of siltation in approximately 19,000 m^2 of the protected area;
- Estimated 6000 m^3 of sediments accumulation;
- Permanent damage to some Fauna and Flora;
- Turbidity analysis above the limit (> 1101 ntu). Environmental limit: 100 NTU - CONAMA 356;
- Sedimentable materials analyses above the legal standard 1ml / l / hour - CONAMA 430;
- Part of the Stream bed totally silted.

Picture 12. Sediments accumulation

For purposes of preventing sediments impacts during earthmoving activities in future RSAs construction, it is strongly recommended to carry out specific actions in which present the potential to improve the drainage capacity of the sedimentation basin rather than adopting a new technical project regarding sediments controlling devices, which certainly would be more costly.

Some of the actions have been already set and accomplished by the environmental impact event by plant personnel. They are of small term and include:

1) Environmental Incident Record in the same day of the event;
2) Cleaning of Sedimentation Basins of ARB 6;
3) Sedimentation basin heightening
4) Implantation of preliminary containment bunds in the dikes of RSA 6;
5) Implantation and coating of drainage routes;
6) Manual Removal of Sediments from the impacted ecosystem;
7) Construction of a contention dike downstream to the sedimentation basin.

The pictures below represent the actions being carried out off the impacted ecosystem with focus on external devices. They start to be implemented by the project in May and finish in August.

Picture 13: Restoration efforts.

2

3

4

5

Action 6 and 7 were also carried out in the period from October to December 2017, being developed within the disturbed ecosystem. In this period, the impacted stream had its bed totally harden as the pictures in below:


Picture 14. sediments removal results


Figure 15. Contention dike.

So that action 6 aimed to remove sediments banks on the foot of the remaining trees aiming to conserve the remaining individuals and action 7 adopted a contention dike and 2 tube as draining spillways to relief water storage, allowing runoff to downstream sections since sediments are decanted through weight difference by the support of the dike structure.

It is very important to remove the part that eventually will sediment after the rains have finished by May 2018, avoiding create an extremely sediment area where native plants might not germinate and establish.

It is expected that the first signals of small fish life returning will be noted by the end of those rains.

The images below represent the result of those 2 actions combined, where there are small water courses recently formed along with some ponds. Hence there was a significant increase in water availability.

Picture 16 Water course.


Picture 17. Ponds.

Finally, the medium and long term recommended actions are cited in below.

Medium term actions:

1) Contract Degraded Area Recovery Plan (DARP);
2) Control of slope erosions and ravines;
3) Execution of surface drainage project on slope
4) Start of the PRAD at the end of the rainy season;

Long term actions:

1) Continue the PRAD during the dry season (second semester);
2) Environmental monitoring of recovery indicators for 2 years;

5) CONCLUSION

Industrial activities that have the potential to cause environmental impact should always carry out preliminary studies to determine how to mitigate impacts in light of local environmental legislation. The depth of the study should be proportional to the potential impact. In the case of mining activity which applies for the work presented here, the occupied area, as investigated here can influence the ground water recharge and consequently have a significant impact on the springs and its fragile ecosystem.

Initial studies will significantly provide information for the development of a consistent strategy to address the environment impact as the footprint increases throughout the area to be occupied by the industry along its operational life. The correct sizing of sedimentation basin, for example, will avoid springs contamination by carried out soil from the dikes of reservoirs during the construction period and rainy season.

The current practice as recommended by existing legislation does not consider engineering preliminary assessment to determine background conditions. The survey carried out was done in several areas that have been built in areas where there was already a significant impact on footprint. The studies show that the volume of ground water ultimately impacted by the recharge area will impact on the volume of flow out of the springs especially on the rainy season.

The strategy for long term occupation should consider the development of a model to predict the impact on the springs which eventually will be detrimental to the ecosystems. The good data now collected would be used to develop and calibrate the model. However, this could be done in earlier years to provide more reliable guidelines for future occupation.

REFERENCES

Araújo, E.P et al. Delimitação das bacias hidrográficas da Ilha do Maranhão. IN: Brazilian Symposium of Remote Sensing, Natal. Anais **XIV Brazilian Symposium of Remote Sensing**: INPE, p. 4631-4638, apr.2009. P 4631 – 4638.

BRAZIL. CONAMA 357/05 - National Environmental Council. Provides about the classification of terrestrial water bodie and establishes conditions and standards of effluents, and provides other measures. **Brasília**, Federal District, p. 1 – 27, may. 2005. Available at: < http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=459>.

BRAZIL. Federal Law 12651/13 - New Brazilian Forestry Code Brasília. Provides about Native Vegetation Protection. **Brasilia**, Federal District, p. 1 – 38, may.2012. Available at: <http://www2.camara.leg.br/legin/fed/lei/2012/lei-12651-25-maio-2012-613076 normaatualizada-pl.pdf >. Accesses in: Sep.2017.

Environmental Protection Agency – EPA. Streamflow. In: Environmental Protection Agency. Volunteer stream monitoring: a methods manual. **Washignton**: EPA 1997. Cap. 1, p. 134-138.

Ivanauskas, N. M et al. Aspectos ecológicos de um trecho de floresta de brejo em Itatinga, SP: florística, fitossociologia e seletividade de espécies**. Revta brasil. Bot**, São Paulo, 20 (2), p.139-153, dez. 1997.

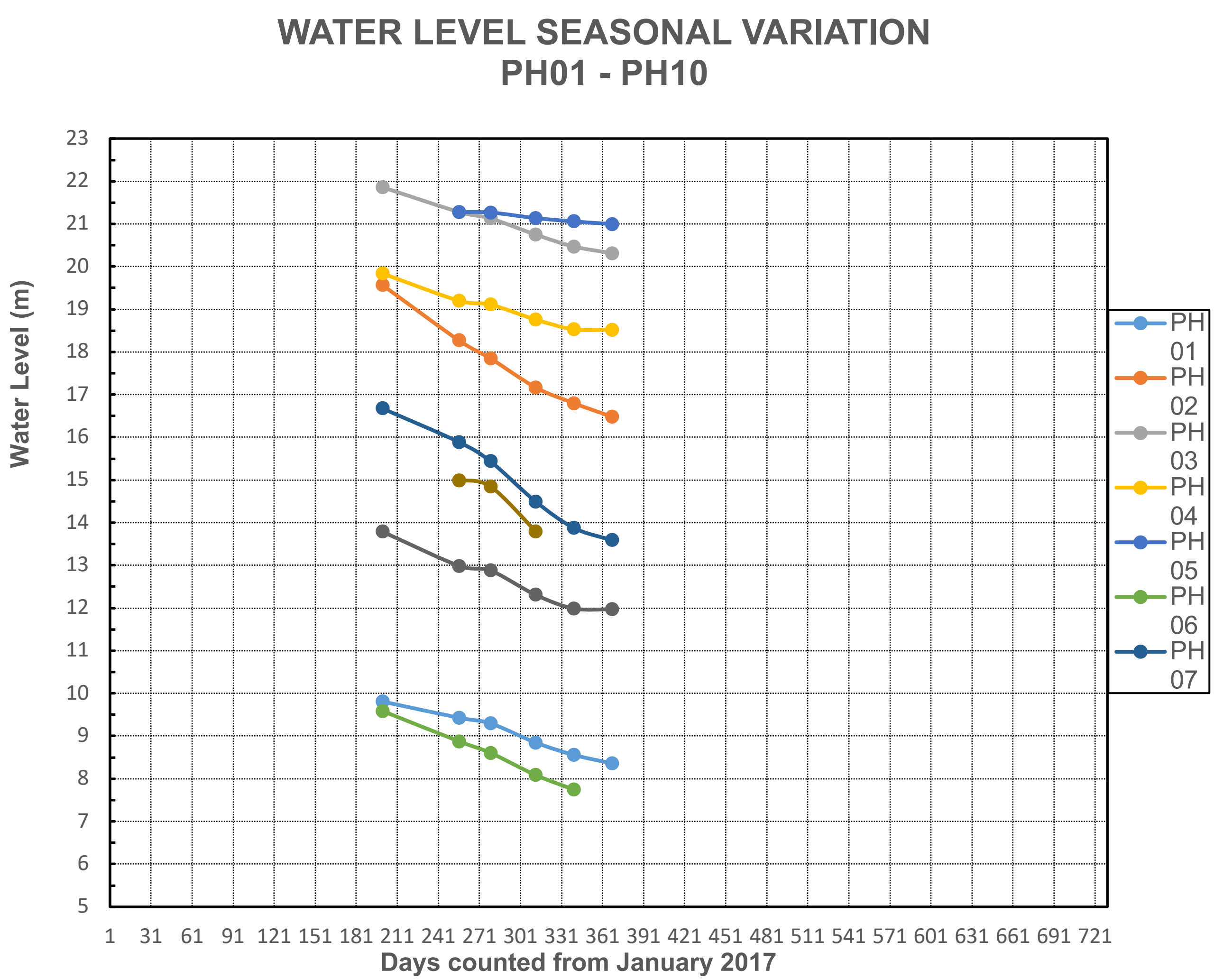
RIBEIRO, C.A.A.S et al. The Challenge of Delineation of Permanent Preservation Areas. **Árvore**, Viçosa-MG, 29 (2), p.203-212, nov 2005

ROMAGNOLO, M. B; SOUZA, J. C. *Análise Florística e Estrutural de Florestas Ripárias do Alto Rio Paraná, Taquaruçu***, MSl. Acta bot. Bras**, Maringá, 14(2): p. 163-174, fev. 2000.

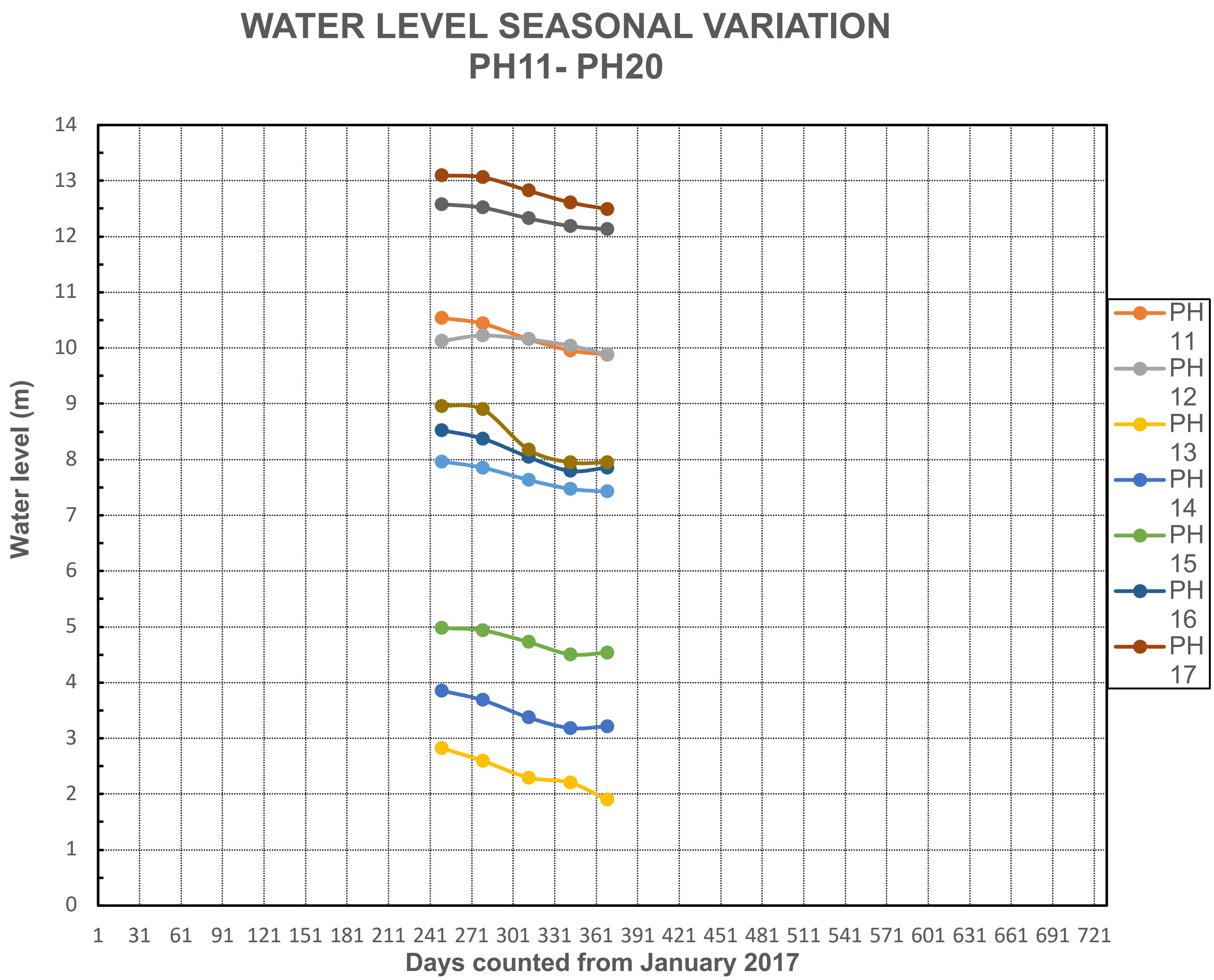
SÃO LUÍS. Bylaw 4669/06 - Provides about São Luís Master Plan. São Luís, p. 1 – 20, oct.2006. Available at < https://www.saoluis.ma.gov.br/midias/anexos/1188_8-lei_n.4.669_de_11.10.2006_d.o.m._n.195_-_completo.pdf>. Accesses in: Mar.2017.

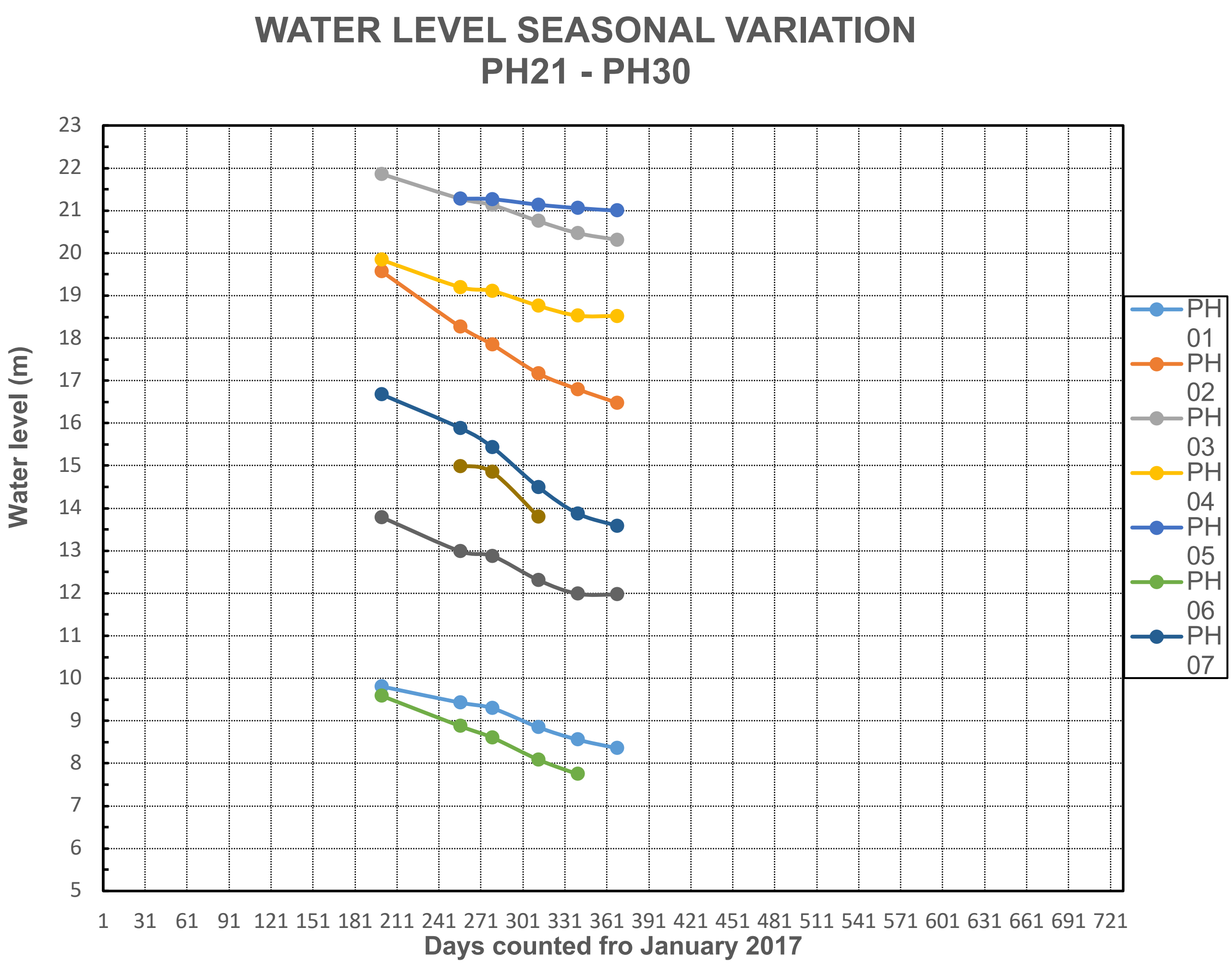
Appendix 1

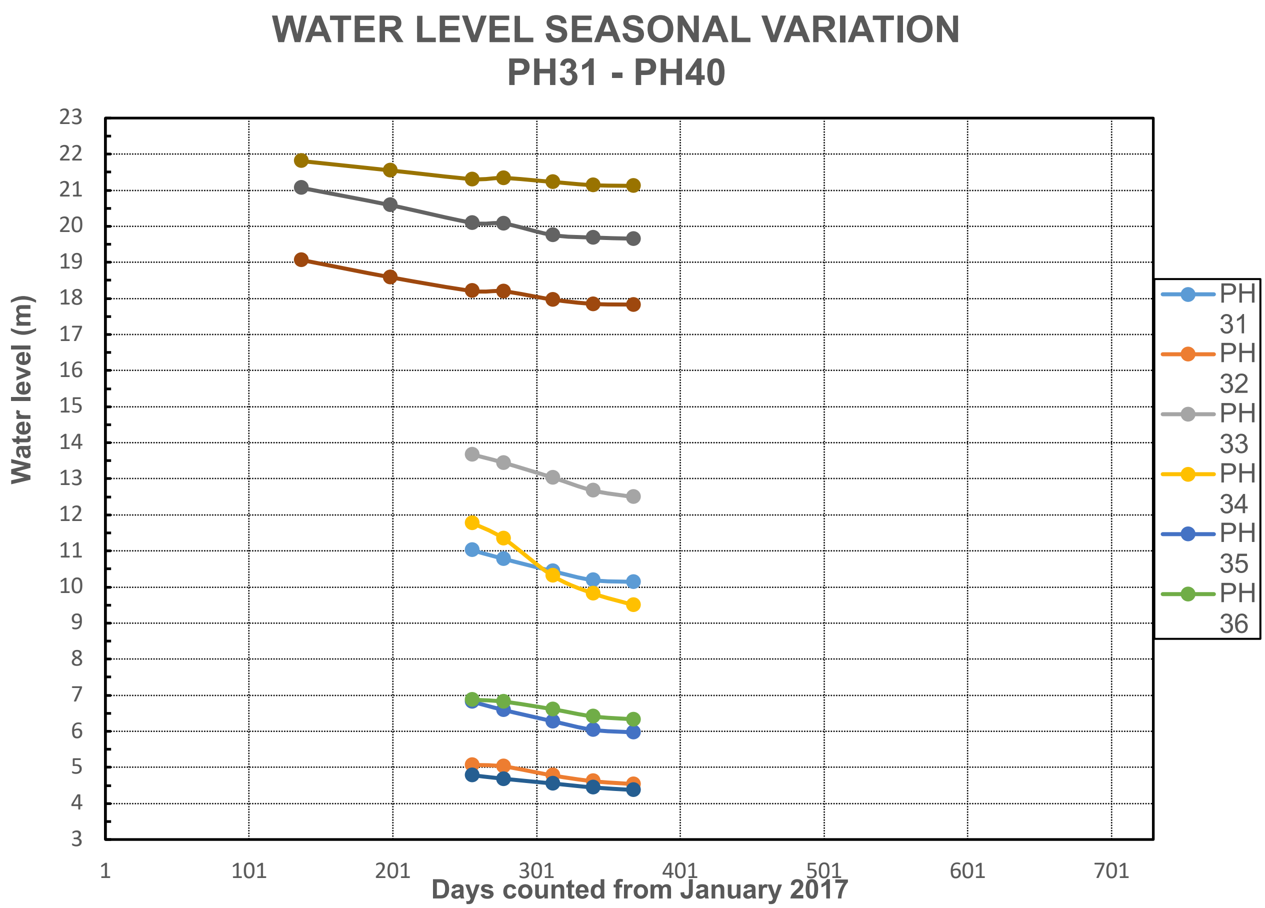
GROUND WATER FLUCTUATION

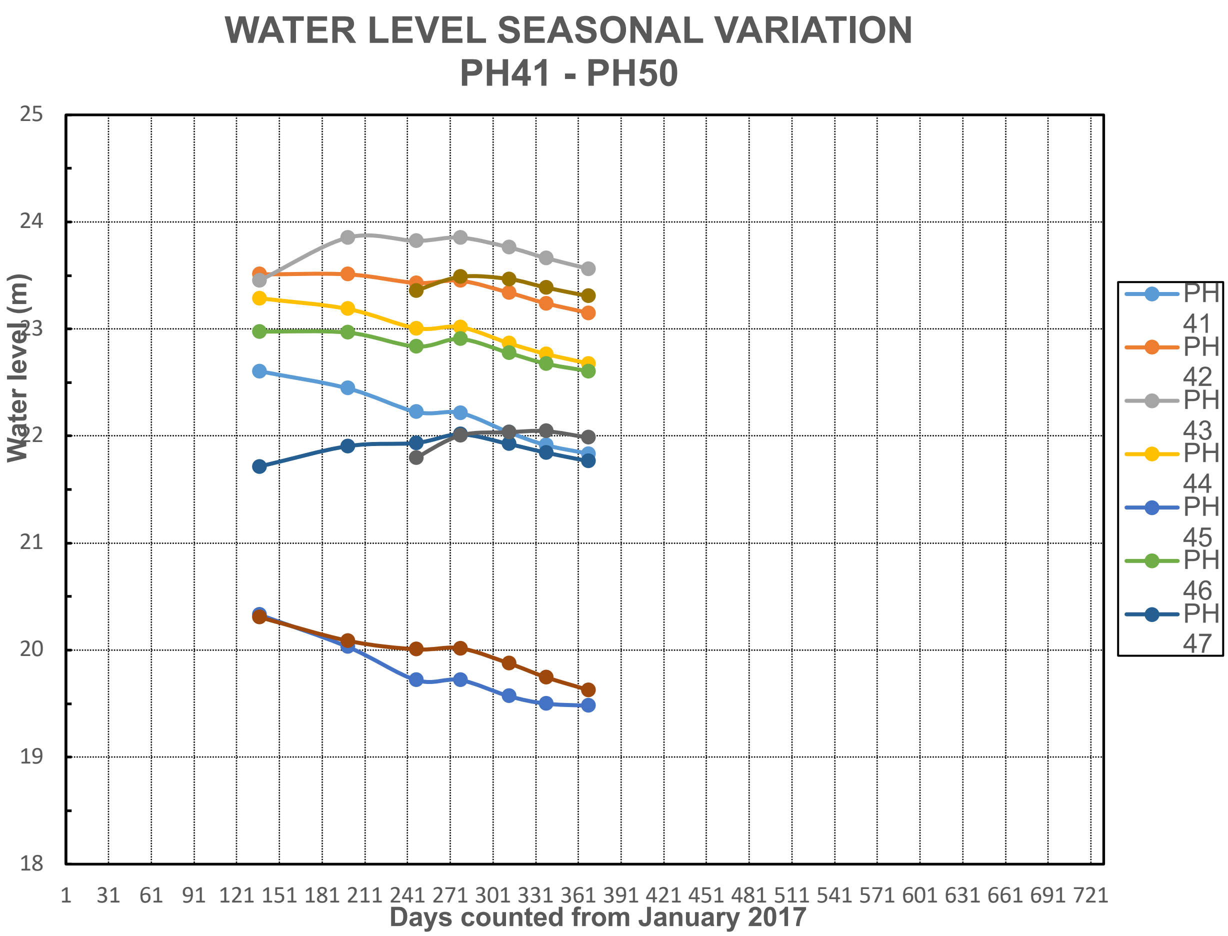


WATER LEVEL SEASONAL VARIATION
PH01 - PH10
Water Level (m)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
1 31 61 91 121 151 181 211 241 271 301 331 361 391 421 451 481 511 541 571 601 631 661 691 721
Days counted from January 2017
PH 01
PH 02
PH 03
PH 04
PH 05
PH 06
PH 07

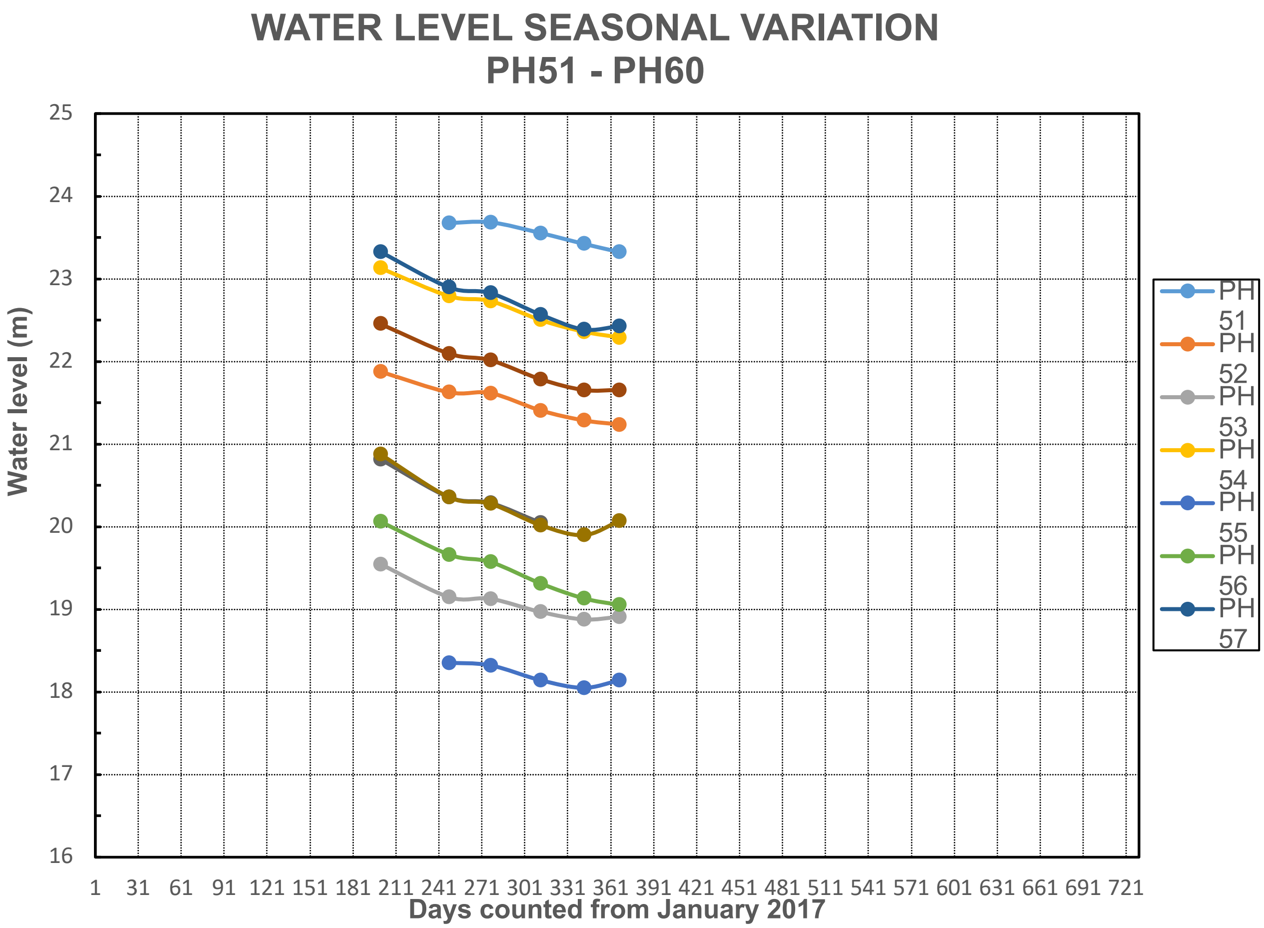

WATER LEVEL SEASONAL VARIATION
PH11- PH20
Water level (m)
Days counted from January 2017
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1
31
61
91
121
151
181
211
241
271
301
331
361
391
421
451
481
511
541
571
601
631
661
691
721
PH 11
PH 12
PH 13
PH 14
PH 15
PH 16
PH 17


WATER LEVEL SEASONAL VARIATION
PH21 - PH30
Water level (m)
Days counted fro January 2017
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
1
31
61
91
121
151
181
211
241
271
301
331
361
391
421
451
481
511
541
571
601
631
661
691
721
PH 01
PH 02
PH 03
PH 04
PH 05
PH 06
PH 07


WATER LEVEL SEASONAL VARIATION
PH31 - PH40
Water level (m)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
1
101
201
301
401
501
601
701
Days counted from January 2017
PH 31
PH 32
PH 33
PH 34
PH 35
PH 36



WATER LEVEL SEASONAL VARIATION
PH41 - PH50
Water level (m)
25
24
23
22
21
20
19
18
1 31 61 91 121 151 181 211 241 271 301 331 361 391 421 451 481 511 541 571 601 631 661 691 721
Days counted from January 2017
PH 41
PH 42
PH 43
PH 44
PH 45
PH 46
PH 47


WATER LEVEL SEASONAL VARIATION
PH51 - PH60
Water level (m)
25
24
23
22
21
20
19
18
17
16
1 31 61 91 121 151 181 211 241 271 301 331 361 391 421 451 481 511 541 571 601 631 661 691 721
Days counted from January 2017
PH 51
PH 52
PH 53
PH 54
PH 55
PH 56
PH 57