# Investigation of the groundwater situation in Pesé stream area, Panama

-A Minor Field Study-

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## Abstract

This study was performed together with the University of Technology in Panama. The purpose of the study is to give a general view of the groundwater situation in the watershed of Pesé stream, located in Panama in an area with low precipitation called the Dry Arc of Azuero. In the report a joint database with information of wells in the area has been established. Hydrogeology has been studied together with discharges from wells in order to give approximate locations of the aquifers in the area. The water use has been reviewed and the water supply capacity of the aquifers estimated. The water quality has been evaluated and the threats towards the fresh water are described. The aim was also to make the compilation of groundwater information available for the public and for all authorities responsible for the water supply.

**Keywords:**
Groundwater, watershed, well, database, hydrogeology, aquifer, discharge, water use, water supply, water quality and fresh water.

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## Preface

This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida/Asdi.

The MFS Scholarship Programme offers Swedish university students an opportunity to undertake two months of field work in a country in Africa, Asia or Latin America. The results of the work are presented in a report at the Master's degree level, usually the student's final degree project. Minor Field Studies are primarily conducted within subject areas that are important from a development perspective and in countries supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the Swedish human resources cadre for engagement in international development cooperation.

The International Office at the Royal Institute of Technology, KTH, Stockholm, administers the MFS Programme for the faculties of engineering and natural sciences in Sweden.

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# Summary

In parts of the tropical zones of the world it hardly rains during the dry periods which can cause shortage of fresh water. In Panama there is an area called the Dry Arc of Azuero, *Arco Seco*, which has this kind of problem. Poor land use contributes further to water problems in the area and besides this, the documentation of water resources is insufficient and the water quality is poor.

The purpose of this study is to give a view of the groundwater situation in the watershed of Pesé stream, located in the Dry Arc of Azuero. The study was performed together with the University of Technology in Panama which has done other investigations related to poor land use and water problems in the same area.

In Panama information and responsibility of the water supply is divided between four different authorities and there is little cooperation between them. In this project the information of the wells in the study area has been gathered together in a joint database. The database is meant to function as a model for continuous future documentation of well information as well as a tool when investigating the groundwater situation.

Investigations of the hydrogeology and evaluations of the discharges from the wells have been performed in order to locate the aquifers but there is lack of information and the hydrogeology in the area is complex why the results are approximate. The aquifers are mainly situated in weathered rock layers, but also in pores in fresh rock and in fracture zones. Estimations of the horizontal boundaries of the aquifers have been done in GIS programs by using information from measurements and documented well drilling data. These estimations are very approximate and can not be used for exact localisations of the aquifers.

The water use has been reviewed and the water supply capacity of the aquifers has been estimated. According to observations and calculations there should not be any major water supply problems in the study area, but the input data is not very reliable and the water resources could be much smaller than the calculations in this study show.

The water quality has been evaluated and the threats towards the water resources are described. The surface and groundwater quality is not good in the study area, but the groundwater quality is good enough for drinking if chlorine is added. Mainly the surface water, but also the groundwater, is exposed by discharges from agriculture, domestic sewage and industries. This affects the water quality badly, especially during the rainy period. Other threats are the exhaustion of the aquifers and changes of the climate.

In the future better documentation of the well drillings needs to be done and a better cooperation between the water supply authorities must be established in order to improve the management of water resources.

# Sumario (Summary in Spanish)

En partes de las zonas tropicales del globo terrestre no hay casi nada de lluvia durante los periodos secos, lo cual puede causar escasez de agua dulce. En Panamá hay un área que se llama Arco Seco que tiene este problema. El mal uso del suelo contribuye a un mayor problema de escasez de agua en el área. Además la documentación es insuficiente y la calidad de agua es mala.

El objetivo de este estudio es hacer una descripción de la situación de agua subterránea en la cuenca de la Quebrada Pesé, situada en el Arco Seco de Azuero. El estudio fue realizado junto con la Universidad Tecnológica de Panamá que ya ha hecho otras investigaciones relacionadas a problemas de agua en la misma área.

En Panamá la información y la responsabilidad se encuentran  divididas en cuatro autoridades y la cooperación entre ellas es mala. En este proyecto la información de los pozos en el área de estudio ha sido reunida en una base de datos conjunta. Lo que se propone es que la base de datos pueda servir como un modelo para la documentación continuada de los pozos y sirva de herramienta cuando la situación del agua subterránea se examine.

En este estudio han sido hechas investigaciones de hidrogeología y evaluaciones de descargas para localizar los acuíferos. Sin embargo falta información y la hidrogeología en el área es compleja, lo cual hace los resultados aproximados. Los acuíferos se encuentran principalmente situados en capas de roca meteorizada, pero también en poros en la roca sana y en zonas de fracturas. Estimaciones de los límites horizontales de los acuíferos han sido hechas en GIS-programas usando información de mediciones y datos de perforaciones documentadas de pozos. Estos estimaciones son muy aproximados.

El uso de agua ha sido revisado y la capacidad del abastecimiento de agua de los acuíferos ha sido estimada. Según observaciones y cálculos no hay grandes problemas de abastecimiento de agua, pero la inseguridad sobre el ingreso de datos en estos cálculos es alta y los recursos hídricos pueden ser más pequeños de lo que los cálculos indican.

La calidad del agua ha sido evaluada y las amenazas de los recursos hídricos han sido descritas. La calidad del agua de superficie y subterránea no esta bien en el área del estudio, pero el agua subterránea es adecuada para ser usada como bebida si se le agrega cloro. Principalmente el agua de superficie, pero también el agua subterránea, están afectadas por vertimientos de desechos de agricultura, domésticos e industriales. Esto afecta la calidad de agua negativamente, especialmente durante los períodos de lluvia. Otras amenazas son el agotamiento de los acuíferos y los cambios en el clima.

En el futuro se tiene que mejorar la documentación de las perforaciones de pozos, y se tiene que establecer una mejor cooperación entre los responsables para mejorar el manejo de los recursos hídricos.

## Sammanfattning (Summary in Swedish)

I delar av jordens tropiska zon regnar det nästan ingenting under torrperioderna vilket kan orsaka sötvattenbrist. I Panama finns ett område som kallas Azueros Torra Båge, *Arco Seco*, som har det här problemet. Felaktig jordanvändning bidrar till ytterligare vattenproblem i området. Dokumentationen av vattenresurser är dessutom otillräcklig och vattenkvaliteten är dålig.

Syftet med denna studie är att ge en bild av grundvattensituationen i avrinningsområdet till Peséån, beläget i Azueros Torra Båge. Studien utfördes tillsammans med Tekniska Universitetet i Panama som har gjort andra undersökningar relaterade till felaktig jordanvändning och vattenproblem i samma område.

I Panama är informationen och ansvaret uppdelat mellan fyra olika myndigheter och samarbetet mellan dem är dåligt. I detta projekt har informationen om brunnarna i studieområdet samlats ihop i en gemensam databas. Databasen är tänkt att fungera som en modell för kontinuerlig dokumentation av information från brunnar och vara ett redskap då grundvattensituationen undersöks.

I denna studie har undersökningar av hydrogeologi och utvärderingar av flöden från brunnarna gjorts för att lokalisera akvifererna. Dock saknas det en hel del information och hydrogeologin i området är komplex vilket gör resultaten ungefärliga. Akvifererna är främst placerade i vittrade berglager, men också i porer i ovittrat berg och i sprickzoner. Uppskattningar av akvifernas horisontella avgränsningar har gjorts i GIS-program genom att information från mätningar och dokumenterade borrningsdata av brunnar har använts. Dessa uppskattningar är mycket approximativa och de kan inte användas för exakt lokalisering av akvifererna.

Vattenanvändningen har granskats och akvifererans vattentillförselkapacitet har uppskattats. Enligt observationer och uträkningar ska det inte finnas några stora vattentillförselproblem i studieområdet, men osäkerheten vad gäller indata i dessa beräkningar är hög och vattenresurserna kan vara mycket mindre än uträkningarna visar.

Vattenkvaliteten har utvärderats och hoten mot vattentäkterna har beskrivits. Yt- och grundvattenkvaliteten är inte bra i studieområdet, men grundvattnet är tillräckligt bra för att användas som dricksvatten om klorid tillsätts. Främst ytvattnet, men också grundvattnet, drabbas av utsläpp från jordbruk, hushåll och industrier. Detta påverkar vattenkvaliteten negativt, speciellt under regnperioden. Andra hot är utmattning av akvifererna och klimatförändringar.

I framtiden måste bättre dokumentation av borrningarna av brunnar göras, och bättre samarbete mellan myndigheterna som är ansvariga för vattentillförseln måste etableras för att förbättra hanteringen av vattenresurserna.

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## List of abbreviations

| | |
|---|---|
| ANAM | *Autoridad Nacional del Ambiente*, National Department of the Environment, is responsible for the environmental aspects of water used by factories. |
| GIS | Geographic Information Systems. |
| IDAAN | *Instituto de Acueductos y Alcantarillados*, Department of Aqueducts and Sewages, is responsible for domestic water use for communities with more than 1500 inhabitants. |
| KTH | The Royal Institute of Technology in Stockholm, Sweden. |
| MIDA | *Ministerio de Desarrollo Agropecuario*, Department of Agricultural Development, is responsible for the development of irrigation and agricultural water use. |
| MINSA | *Ministerio de Salud*, Health Department, is responsible for domestic water use for communities with less than 1500 inhabitants. |
| UTP | The University of Technology in Panama. |

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# 1 Introduction

## 1.1 Background

Water is necessary for life. All over the world fresh water is needed for, among others, domestic use, agriculture and industry. The water is extracted from the groundwater or from the surface water. If too much water is taken from the groundwater the aquifers can dry out. Groundwater is also threatened by contamination sources and changes in the climate. It is necessary to understand that groundwater is a sensible and exhaustible resource.

In tropical zones of the globe, seasons are divided into dry and wet periods. In general, it hardly rains during the dry periods which can cause shortage of fresh water. One of the countries that have areas with this kind of problem is Panama. On average, Panama has a high yearly precipitation, but there are areas where it does not rain enough. The driest part of Panama is called the Dry Arc of Azuero, *Arco Seco*, and is situated southwest of Panama City, on the Pacific slope, mainly on the Azuero Peninsula. Because of meteorological circumstances and the location between the mountains the precipitation is low. Low precipitation in combination with poor land use in the area, contribute to water problems during the dry seasons.

In the Dry Arc of Azuero groundwater has been used without planning and the communities and the agriculture in the area have been suffering of lack of water. One of the reasons is that local people have cut down the trees, burnt them and use the land for cattle and agriculture. This increases the level of soil erosion and the infiltration of the rainwater is decreased. Another reason for decreasing infiltration is that the organic material is utilized when the trees in the area are cut down. After a few years of agricultural use there is only clay left with very little organic matter.

Another threat to the groundwater is when wastewater from communities and industries is disposed into water bodies without any or very little treatment. It is important to improve the water quality and to establish a water and waste management plan in the area. There is also a great need for assessing the general view of current and future water supply needs and surveying accessible groundwater.

Investigations have been done and are being performed in the Dry Arc of Azuero. The University of Technology in Panama, UTP, is doing some research in one of the watersheds in the area, the watershed of river Rio La Villa. This research is related to the problems with poor land use and water problems in the area.

The authors received an invitation from the University of Technology in Panama, UTP to do the thesis as an investigation of the fresh water in a part of the watershed of Rio La Villa. The thesis is a part of the research that UTP is doing in the watershed. It has been implemented within the framework of the Minor Field Studies Scholarship Programme, MFS.

## 1.2 Purpose and Objectives

The purpose of this study is to make an investigation of the groundwater situation in a part of Rio La Villa watershed, Panama, in order to give a compilation that is available for all authorities and for the public. The objectives are:

- To establish a database of the wells in the area in order to collate information from different sources in one place.
- To localise and classify the aquifers according to discharges in wells.
- To present the geology, how the aquifers are situated and the groundwater flow pattern.
- To give a view of the water use today and a prognosis for the nearby future.
- To estimate how much water the aquifers can supply.
- To evaluate the surface and groundwater quality.
- To describe the main threats today.

## 1.3 Extension and limitations

To limit the research only a smaller area of the Rio La Villa watershed is studied. The study area is selected by following criteria:

- The area should be situated somewhere in the lower parts of the Rio La Villa watershed. This part is more interesting to study since there are more problems with low precipitation there than in the higher parts of the watershed.
- The water supply in the area should come from wells and not from a water treatment plant since the research is about the groundwater.
- One of the main activities in the area should be agriculture because the farmers need water for irrigation from wells.
- The area should include at least one bigger village or a small town to simplify the collection of data and the access to necessary support and information.
- The area should be located close to a bigger town and close to the Technical University in Azuero to have an easy access to equipment and authorities responsible for the water supply in the study area.

The study is mainly based on existing data, but some measurements have been implemented to present how the aquifers are situated. The study only covers about the top 60 meters of the geology. No water is extracted and no investigations have been carried out below this level.

The duration of the collection of data in Panama was restricted to two months from the middle of September to the middle of November 2003 which is in the rain period. Two weeks of this time was used for field studies and measurements in the project area.

# 2 Methodology

A general view of the groundwater situation can be established by following methods:

- Existing information of the area needs to be collected and studied.
- The area should be studied in the field and interviews with water users and those in charge of the water supplies needs to be performed.
- All the gathered information needs to be treated and arranged so that it is finally compiled into an organised and comprehensive presentation.

In Panama City, information of the whole Rio La Villa watershed was studied to get an overview in order to choose a project area. The investigation started by studying existing information to get an idea of what kind of surveys that have been done and what kind of research that needs to be done.

A project area was chosen according to the criteria mentioned in chapter 1.3., Extension and limitations. Information about the water resources in the project area was gained from the different authorities that are responsible for the water supply in the area. The project area was investigated through studies of existing information and field studies with help from the regional centre in Azuero of the University of Technology in Panama and people from the authorities that are in charge of the water supply. Measurements of the water levels were carried out and information was gained from discussions with geologists, people responsible for the water supply and water users. The gathered information was continually arranged and compiled in broad outlines.

In Sweden a more precise arrangement and compilation of the information was made and the report was written. In order to comprehend and facilitate the drawing of conclusions of the groundwater situation, digitalized maps that present some of the well parameters, including the measurements, were prepared. The GIS-programs ArcInfo and ArcView were used for all the electronically handling of the geographic data. A digitalization of the project area was completed in ArcInfo and the wells were plotted by using ArcView. Several maps were made in ArcView to present information of the different wells and estimated interpolations of the discharges and measured values.

The structure of the study starts with a description of the study area, including; location, boundaries, land use and hydrogeology. To facilitate the understanding of technical terms for the reader the next chapter called Technical Aspects explains how a well is constructed. In the Analysis chapter, the water resource data are worked up. The chapter includes a presentation of a database of the wells, an arrangement of the geology in the wells and aquifer characteristics in the area, water use, water supply, water quality and threats. Finally, the results of the project are reviewed and conclusions, recommendations and suggestions for future studies are given.

# 3 Statement of the problems

A Minor Field Study is an excellent experience to learn more about problems that occur in developing countries. Most of the problems are of institutional and cultural clash character but there are also technical problems that can happen in any country involved in a project like this.

## 3.1 Institutional problems and cultural clash

It can sometimes be difficult to separate institutional problems and cultural clash. Cultural clash can be regarded as an institutional problem and therefore these have not been separated in this study.

In Panama the water supply and water management is delegated to four different authorities. The four authorities and their water supply responsibility areas are:

- Department of Aqueducts and Sewages, *Instituto de Acueductos y Alcantarillados* (IDAAN), is responsible for domestic water use for communities with more than 1500 inhabitants.
- Health Department, *Ministerio de Salud* (MINSA), is responsible for domestic water use for communities with less than 1500 inhabitants.
- Department of Agricultural Development, *Ministerio de Desarrollo Agropecuario* (MIDA), is responsible for the development of irrigation and agricultural water use.
- National Department of the Environment, *Autoridad Nacional del Ambiente* (ANAM), is responsible for the environmental aspects of water used by factories.

There is little cooperation between the different departments and there is no system to coordinate information between them. Much time was spent on visiting the different authorities and finding the people with the information that was needed. Most of the time a paper was wanted which confirmed the justification of the study from the head of the Civil Engineer faculty at UTP. Especially in Panama City, at the head quarters of the authorities, is the information that exists of the water resources difficult to get access to, both for experts and public. The authorities are careful to share information, probably because they are afraid that they will loose their importance if they give out too much information from their responsibility areas. There exists a departmentalization of work responsibilities which needs to be changed if the handling of water resources shall be improved. If investigations of the water resources shall be successful and give relevant results there must be a more open mentality to share information. Because of the lack of spreading information there is a risk that unnecessary research is done that has already been done before. One of the main focuses of this study is to compile well data and make it available to all the authorities and to the public.

The people in Panama are very polite and want to help even if they cannot and this can be both confusing and misleading. People usually give an answer to a question even if they do not know the answer which means that the reliability of the facts about the wells can sometimes be questioned since some of the information has been received orally.

The documentation of the well drillings is insufficient. Usually there is no documentation of non successful drillings when water was not found and there is not enough documentation concerning the drilling of the wells that are in use. This makes it more difficult to draw conclusions about the aquifers.

There are no regulations of the groundwater in the Panamanian law. An environmental management plan for the groundwater is needed.[1]

People in general do not think and act in a way what is best for the community, only what is best for them. For example, the well owners do not want the neighbours to use water from their well even though there is enough in the well and the neighbour does not get enough water.[2]

## 3.2 Technical problems

**Language**
In Panama, the official language is Spanish. In the countryside, very few people speak English, while the knowledge of English is better in the capital. Having questions, technical discussions and the majority of the literal information in Spanish is both a challenge and a problem when not having a complete mastery of the Spanish language. It can also cause misunderstandings and it is time consuming.

**Rain and dry period**
The investigation of the area including all the measurements was implemented during the rain period. Since the main water supply problems occur in the dry seasons, the measurements would have been more interesting if they had been implemented in the dry period too. It is difficult to get the right view of the water problems when the field study is only limited to one period.

**Computer software**
A digitalization of the project area was done in Panama by using the GIS-software ILWIS. Electronically handling of data was not continued in ILWIS in Sweden because it was more practically to use other GIS-software.

[1] Lic.Gonzalo A. Menéndez G General Assistant Manager ., ANAM, 2003-09-25
[2] Lic. Manuel Ruiz, irrigation responsible in the project area, MIDA, 2003-10-22

# 4 Description of the study area

## 4.1 The Republic of Panama


**Fig. 4.1a**: Map of Central America with Panama marked.

The Republic of Panama is situated in Central America on the south-eastern end of the isthmus connecting North America and South America, see figure 4.1a[3]. The country, see figure 4.1b[4], has an area of 78,200 sq km, which is approx. a sixth of Sweden. The population is 2.9 million people and about 708,000 of them live in the centre of the capital city Panama City[5]. The official language is Spanish but English and a number of Indian languages are spoken in different areas. The form of government in the county is constitutional republic.

Panama became independent in 1903, except for the Canal Zone which the USA had under their control until the first of January 2000. The country has a significant geographic position and has for centuries served as a land bridge and transit zone between continents and oceans. The dominant feature of the landform of Panama is a central spine of highlands forming a continental divide. The highest elevations are near the borders to Costa Rica and Colombia. The lowest elevations are at the waist of the country where it is crossed by the Panama Canal. Most of the population is concentrated on the Pacific side of the country in Panama City and southwest of the city. The terrain in the interior is mostly steep, rugged mountains and dissected. In the upland plains and in the coastal areas is the terrain largely plains and rolling hills. Panama has a tropical climate with high temperatures and humidity all the year round. The long rain season occurs between May and December in almost the whole country and the short dry season is between December and April.


**Fig. 4.1b**: Map of the Republic of Panama.

[3]:Offshore simple, <http://www.offshoresimple.com/images/panama_map.gif>, (2004-02-25)
[4]Yahoo, <http://us.i1.yimg.com/us.yimg.com/i/travel/dg/maps/ee/750x750_panama_m.gif> , (2004-02-25)
[5]Central Intelligence Agency, <http://www.odci.gov/cia/publications/factbook/geos/pm.html#Intro>, (2004-02-25)

## 4.2 The study area

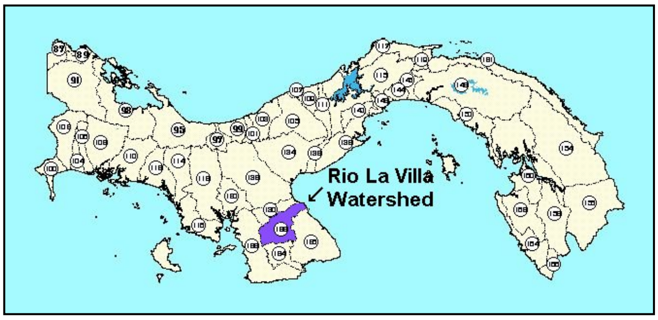


**Fig. 4.2a**: Map of the watersheds in Panama.

Panama has 52 watersheds[6]. One is Rio La Villa, see figure 4.2a[7], with an area of about 1000 $km^2$. A part of this watershed was chosen as the study area. It was selected by criterions written in chapter 1.3, Extension and limitations.

The area around Pesé stream was selected as the study area, see figures 4.2b[8] and 4.2c. It is situated in the lower parts of the watershed and is close to the bigger towns Chitré and Los Santos. The bigger village, Pesé is within the limit of the area to the west. There are also several farmers that use irrigation in the area. All the water supply in the area is from wells i.e. from the groundwater.

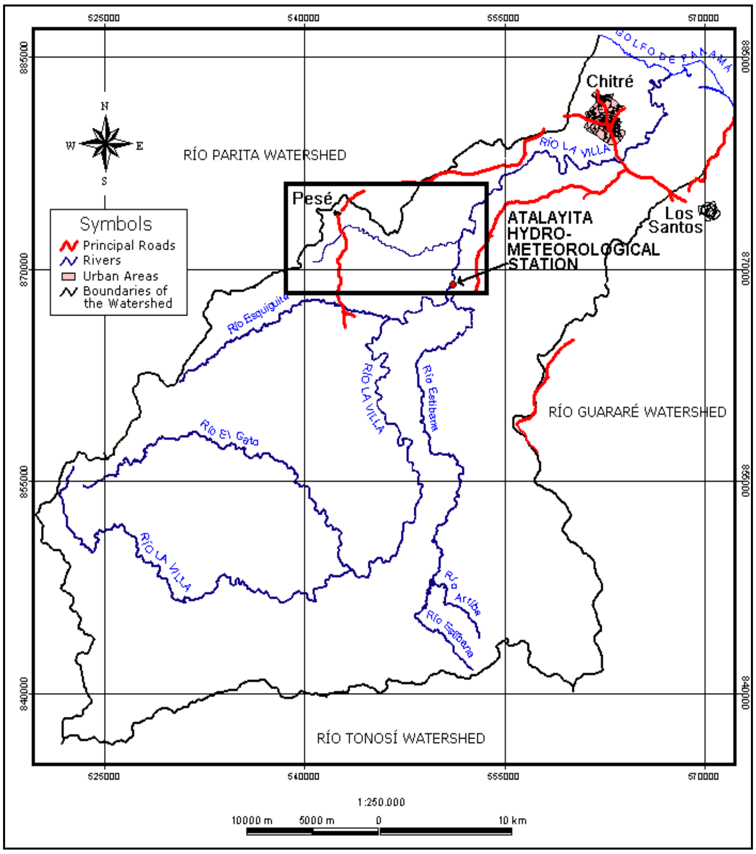


**Fig. 4.2b**: Map of Rio La Villa watershed with Pesé watershed marked with a square.

[6]Hidrometeorología República de Panamá, ETESA, <http://www.hidromet.com.pa>, (2004-03-16)
[7]Hidrometeorología República de Panamá, <http://www.hidromet.com.pa/images/ panamacuencas02.jpg> , (2004-02-25)
[8] Autoridad Nacional del Ambiente, ANAM, *Proyecto Piloto de Monitoreo de la Calidad del Agua de la Cuenca del Río La Villa, Provincias de Herrera y Los Santos y su aplicación en las Principales Cuencas Hidrográficas de Panamá*, Panama: Arden & Price Consulting/CH2 MHill, April 2003.

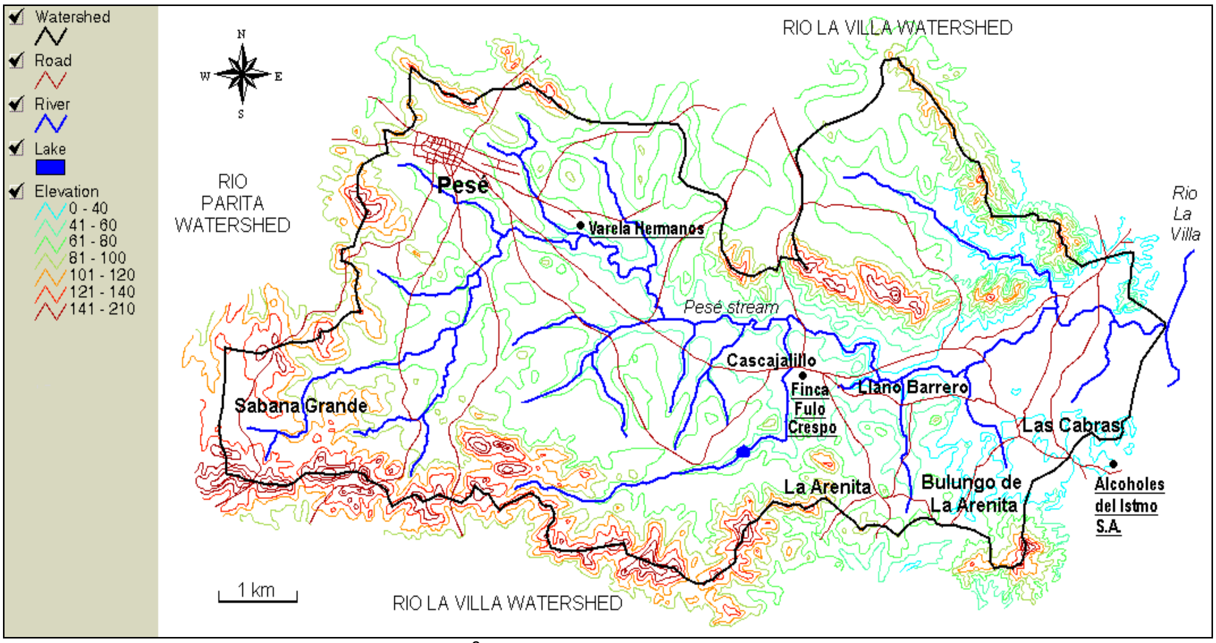


**Fig. 4.2c**: Map of Pesé watershed.[9]

The study area is a small watershed of the big Rio La Villa watershed and the boundaries are the hills around the Pesé stream, the watershed divider. The river Rio La Villa is situated to the east and another watershed, Rio Parita watershed, is situated to the west, see figure 4.2c.

The Pesé stream area is less than 50 km$^2$. The village Pesé has a population of approx. 2600 inhabitants and there are approx. 1800 inhabitants on the countryside in the project area[10]. There are several farmers and most of them use irrigation during the dry months, January - May. In the higher elevated parts and in places where it is difficult to find enough water for irrigation pastureland is common. There are two industries in the area and one in the outskirt. One of the industries is a pork breeding farm, Finca Fulo Crespo. It is situated in the middle of the study area. The other two are alcohol distillery factories. The one situated in the project area, Varela Hermanos, is one kilometre southeast of Pesé, and the other one, Alcoholes del Istmo S.A., is situated in the outskirt, in the very east of the project area. See figure 4.2c. These industries need sugarcanes for their production and because of this there are sugarcane plantations in the area. Some pictures from the watershed are presented in appendix, see Appendix A. The mean value of the temperature is approx. 28°C during the whole year and the mean value of the precipitation is approx. 1400 mm/year. Most of the rain comes during the rain period. The rain period is in almost the whole country during the seven months June to December. The dry period is during the five months January to May.

[9] Digitalization from the map: *Pesé, Hoja 4039 I, serie E762, 1:50000*, Intituto Geografico Nacional, "Tommy Guardia", Edición 2 – IGNTG
[10] Contraloría General de la República de Panamá, Censos Nacionales Población y Vivienda 2000, Resultados Finales Básicos: Totales del País, Recieved from IDAAN

## 4.3 Hydrogeology

### 4.3.1 Geology

#### 4.3.1.1 In general in the watershed of Rio La Villa

A general view of the outcrop geology in the watershed of Rio La Villa is gained from a geological map of the watershed of Rio La Villa, created from satellite photos; see figure 4.3.1a[11] and the legend, table 4.3.1[12]. These give the information that the outcrop consists of sedimentary and igneous rocks. Sedimentary rock is formed from the weathered remains of other rocks that have been transported, sedimented and pressed into layered solids.[13] Sedimentary rocks are usually good aquifers since they often consist of many pores. The igneous rocks are formed when molten rock cools and solidifies and they are divided into two groups: intrusive rocks, or plutonic rocks, when they are produced from magma underground; and extrusive rocks, or volcanic rocks, when they are formed by rapid cooling of erupted lava at the Earth's surface.[14] The soil in the area consists mainly of clay, with little organic matter.

According to the geologist Leonidas Rivera the geology formations contain mostly of volcanic rock.[15] Volcanic rock literally means igneous extrusive rock, but the term is sometimes used for other rocks as well. There are various opinions of how to define the different categories and the different rock groups are not distinctly separated. Sedimentary rocks formed from the remains of volcanic rocks can have properties that are similar to the volcanic rocks. Tuff, for example, seems to lie between the categories of igneous and sedimentary rock since it is a compacted sediment of volcanic origin.

Volcanic geology is complex and that is a reason why there is little information about the geology in this area.[16] The rapid cooling of lava, that forms the extrusive igneous rocks, or volcanic rocks, generally does not allow mineral crystals to grow large enough to be seen with the unaided eye and that is why volcanic rocks usually are fine-grained in their texture.[17]

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[11] Ing. Leonidas Rivera, *Mapa Geomorfológico, Cuenca del Río La Villa*, from the presentation: Sistema de información geográfica aplicado a la micro zonificación de zonas de alta vulnerabilidad a los deslizamientos en las cuencas de los ríos Chiriqui Viejo y La Villa , UTP: March 2002.

[12] *Mapa Geológico, Panama*, Ministerio de comercio e industrias, Dirección general de recursos minerales, República de Panamá

[13] Wikipedia, <http://en.wikipedia.org/wiki/Sedimentary_rock>, (2004-01-20)

[14] Department of Geological Science and Center for Los Angeles Basin Subsurface Geology at Calefornia State University, Long Beach, <http://seis.natsci.csulb.edu/basicgeo/IGNEOUS/IGNEOUS.html>, (2004-01-19)

[15] Ing. Leonidas Rivera A., Facultad de Ing. Civil, UTP, 2003-09-23

[16] Lic. Gonzalo A. Menéndez G., Assistant Manager, ANAM, 2003-09-25

[17] Department of Geological Science and Center for Los Angeles Basin Subsurface Geology at Calefornia State University, Long Beach, <http://seis.natsci.csulb.edu/basicgeo/EXTRUSIVE/EXTRUSIVE.html>, (2004-01-20)

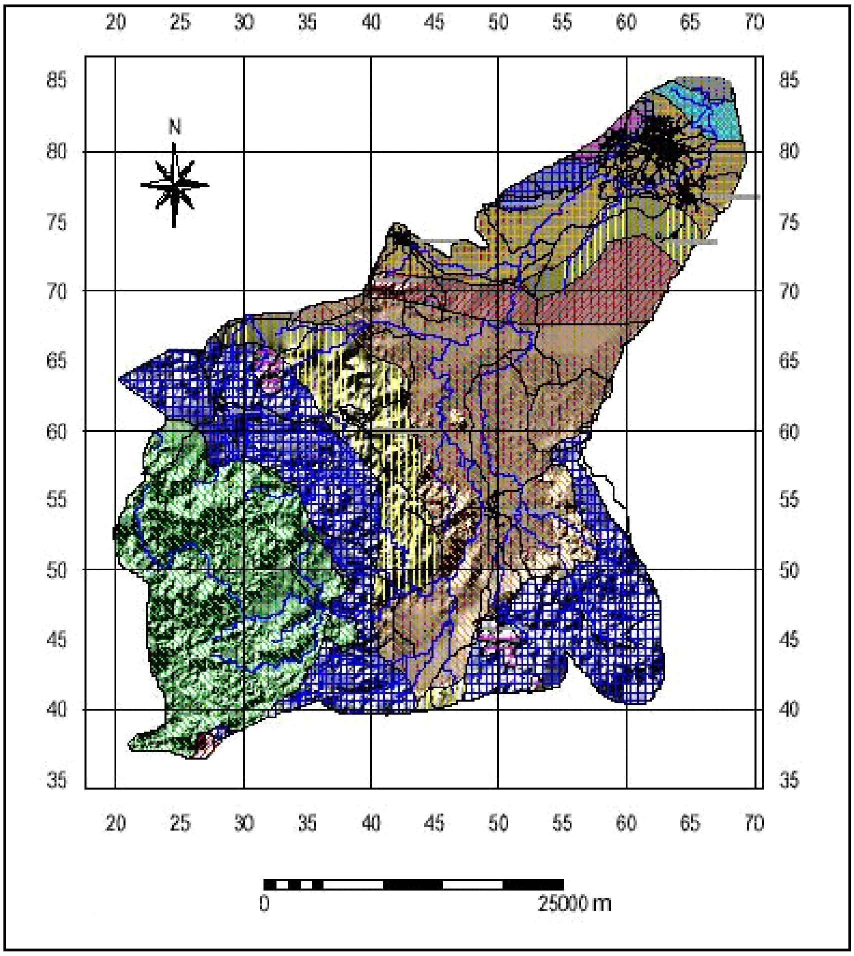


**Fig 4.3.1a**: Geological map of the Rio La Villa watershed.

**Table 4.3.1**: Legend to the Geological map.

| | Legend to geological map | | | | |
|---|---|---|---|---|---|
| | **Designation** | **Formation** | **Substance** | **Rocktype** | **Period** |
| | QR-Aha | Rio Hato | conglomerate, sandstone shale and tuff | sedimentary | Quaternary |
| | TEO-RIQ | Valle Riquito | quartzdiorite and gabbro | igneous intrusive | Tertiary |
| | TEO-TO | Tonosi | shale and sandstone | sedimentary | |
| | TO-MAC | Macaracas | tuff and sandstone | sedimentary | |
| | TO-MACpe | Pesé | tuff, sandstone and limestone | sedimentary | |
| | K-CHAo | Ocú | limestone and tuff | sedimentary | Cretacious |
| | K – LM | L. Montuoso | quartzdiorite, quartzgabbro granodiorite, quartzmonzonite | igneous intrusive | |
| | k-VE | Playa Venado | basalt and pillow lava | igneous extrusive (volcanic) | |

#### 4.3.1.2 In the Pesé stream area

In the area around the Pesé stream, i.e. the study area, the outcrop geology is from the Pesé formation according to figure 4.3.1a and table 4.3.1. The Pesé formation contains of sandstone, tuff (compacted volcanic ash), and limestone. Since there are no exact boundaries of the formations that are outcropping it is necessary to also look at the vicinity of the Pesé stream watershed. Figure 4.3.1a shows that just north of the watershed of stream Pesé there are outcrops of the Playa Venado formation which consists of basalt and pillow lava. Just south of the watershed is the Ocú-formation, consisting of limestone and tuff. As mentioned earlier, the geological map in figure 4.3.1a has been created from satellite photos and is only a rough description of what kind of outcrops there are in the area. It is difficult to define the geological formations in the area since a detailed geological map does not exist.

In the parts where there are no outcrops there are in general two layers of weathered material above the fresh rock. The top layer consists of clay and has a thickness of 3-12 m. The second layer consists of soft weathered rock which is fragile and a little clayey and has a thickness of around 1-15 m. The lithology classification of the second layer, the weathered rock, is not easy to define because it is difficult to see the texture and the components of the original rock. In most cases the weathered rock is of the same lithology as the underlying fresh rock.[18]

The geologist Ibarra Ruperto, who is supervising most of the well drillings made by MIDA in the area, says that the geology in general in the whole watershed of Pesé stream mainly contains fine grained sandstone. The geology information that exists is very approximate since no cores have been taken in the area. Studies of the well drillings done by the agricultural ministry, MIDA, show that the Pesé stream area primarily contains five kinds of rocks (the most common is listed first): sandstone, basalt, andesite, tuff and conglomerate. Below is a description of these rocks and their aquifer characteristics compiled from discussion with Ibarra Ruperto[19]. Some of the rocks don't agree with the contents of the formations described in the geological legend and their relation to the formations that are in the area, according to the geological map, is uncertain. The descriptions of these five rocks are:

**Sandstone** is a sedimentary rock and the most common rock in the area. In general sandstone is a very good aquifer since it allows water to infiltrate. But, in this case, the sandstone contains very fine grains, which compact easily and therefore do not allow water to infiltrate.  Also, this sandstone is interbedded with shale that has a high content of calcite and that decreases the level of permeability.

[18] Tahal Consulting Engineers LTD, *Proyecto de riego del arco seco informe final – hidrogeología*, May 2003
[19] Ing. Ibarra Ruperto, geologist, MIDA, 2003-11-06.

**Basalt** is an extrusive igneous rock and has been formed from lava that has cooled down on the earth's surface. Basalt is not considered an aquifer in itself because it is compact and dense, but due to the content of fractures in the rock basalt has better aquifer characteristics compared to the fine grained sandstone in this area. Figure 4.3.1c shows weathered basalt.

**Fig 4.3.1c**: Photo of weathered basalt, outcrop close to well 22 (Sabana Grande well 2).

**Andesite** is also an extrusive igneous rock and has similar properties to Basalt. Andesite is considered to be an aquiclude, but since the wells in this rock have a higher discharge than suspected, andesite is considered a fairly good aquifer in some places. The aquifer capacity is probably due to fractures in the rock.

**Tuff** is a compacted sediment of volcanic origin.[20] It is a consolidated pyroclastic sediment, which means that it has been produced by explosive or aerial ejection of material from a volcanic vent.[21] Most tuffs contain coarser crystals or rock fragments surrounded by fine-grained ashy matrix.[22] Tuff is a fairly good aquifer because

**Fig 4.3.1d**: Photo of weathered tuff, outcrop close to well 15 (Bulungo de La Arenita well 1 MINSA).

[20] Richard E. Goodman, *Engineering Geology, Rock in engineering construction*, (United States: 1993), 24
[21] Wenthworth and Williams, <http://www.hanksville.org/voyage/defs/tuff.html> 1932, (2004-03-16)
[22] Richard E. Goodman, *Engineering Geology, Rock in engineering construction*, (United States: 1993), 269

of many pores in the rock and is considered as one of the better aquifers in the area. The weathering of the tuff has produced a soil residual coloured between yellow and red. Figure 4.3.1d shows weathered tuff.

**Conglomerate** is a sedimentary rock which consists of rounded gravel and stone-particles with a fine-grained matrix in between. It's a bad aquifer because it is compound of particles with a wide range of sizes.

### 4.3.2 Geomorphology

**Fig. 4.3.2a**: Photo of the view over Sabana Grande in the watershed of stream Pesé.

The geomorphology in the Pesé stream area is characterized by small, very weathered hills with ditches in between, see figure 4.3.2a. This hummocky topography is a result of the sediment transport made by the surface water. The whole area presents a high level of deforestation which increases the sediment transportation. It is also common with flat areas with steep hills see figure 4.3.2b. In low places and in flat areas the weathered rock layer is in general thicker compared to areas with hills and in sections with a higher elevation. The weathered layer is sometimes non-existent in the hilly and higher located areas and it is even possible to see outcrops of the fresh rock in these areas.

**Fig 4.3.2b**: Photo of Cerro Ramonal in the watershed of stream Pesé.

### 4.3.3 Aquifers

An aquifer is a saturated bed, formation, or group of formations which provides water sufficient to be economically useful. To be an aquifer, a geologic formation must contain pores or open spaces that are filled with water and be large enough to transmit water toward wells at useful rate. A formation which is nearly impermeable and/or through which practically no water moves is called an aquiclude. Formations which give some water, but not enough, are called aquitards. In water-poor areas, a formation producing small quantities of water may be called an aquifer, whereas the same formation in a water-rich area would be an aquitard.

#### 4.3.3.1 Unconfined and confined aquifers

There are two different physical conditions where water can exist in aquifers. These are called unconfined and confined aquifers.

**Unconfined aquifer**, or water table aquifer, see figure 4.3.3a, is the most common condition. The water table in an unconfined aquifer is exposed to the atmosphere through the overlying soil and rock layer. The groundwater level forms the upper boundary of this aquifer and the water table agrees with the static level in a well that is connected to an unconfined aquifer.

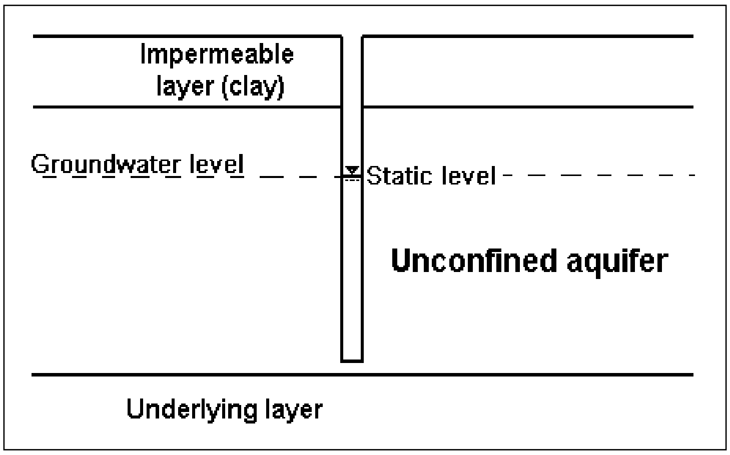


**Fig. 4.3.3a:** Illustration of a well in an unconfined aquifer.

**Confined aquifer**, see figure 4.3.3b, is generally subject to pressures higher than atmospheric pressure.[23] Confined groundwater is isolated from the atmosphere by impermeable geologic formations. The water level of a well installed in a confined aquifer occurs somewhere above its upper boundary. Same aquifer can contain both a part that is confined and another part that is unconfined.

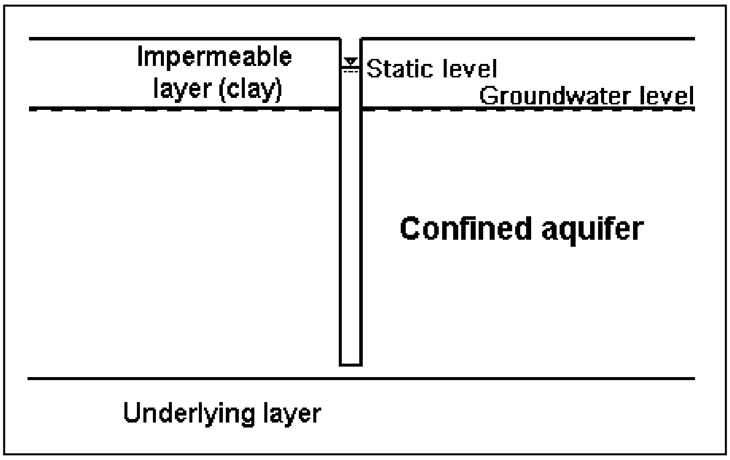


**Fig. 4.3.3b**: Illustration of a well in a confined aquifer.

[23] Fletcher G. Driscoll, *Groundwater and wells*, (St. Paul, Minnesota: John Screens, 2003), 62

Due to the lack of geological research, it is difficult to definitely say if the aquifers in the study area are confined or unconfined. The best way to find out if the aquifer has confined or unconfined characteristics is to look at the static level in a well installed in the aquifer. Most of the rocks are covered with a clay layer which is nearly impermeable. The aquifer is probably confined, if the static level occurs in the impermeable clay-layer. This is due to the pressure in the confined aquifer, which forces the water level in the well to rise higher than the groundwater table. If the static level occurs somewhere in the rock layer where water has been found, the aquifer is most likely unconfined. In this case the water level in the well is at the same level as the groundwater table since there is no pressure.

#### 4.3.3.1 The aquifer types in the study area

It does not exist only one aquifer in the area. Instead there are several different aquifers that are more or less independent of each other. These aquifers are divided into three groups based on their geological characteristics. The three aquifer-types are: Aquifers in weathered layers, Aquifers in fresh rock and Aquifers along the fractures:

**Aquifers in weathered layers** have been formed in the weathered rock horizons. Even though a rock in itself has a very low permeability, the effects of weathering can cause permeability sufficient to store and transmit groundwater. The base of this type of aquifer is the contact between the weathered layer and the unweathered rock, i.e. fresh rock, and is easy to determine when drilling. These aquifers are unconfined and according to the study made by TAHAL[24] this aquifer-type is the most common in the Rio La Villa watershed.

**Aquifers in fresh rock** are generally found in fresh sedimentary rocks. This aquifer layer does not have any distinct boundaries that can be clearly defined. The groundwater in these aquifers is transported through pores in the fresh rock.

**Aquifers along the fractures** are stretched out and restricted to a limited width, associated to fracture lines in the rocks. Sometimes the width is only a few meters and for that reason cases have been found where two wells, situated close to each other, have shown very different hydraulic characteristics.

[24] Tahal Consulting Engineers LTD, Proyecto de riego del arco seco informe final – hidrogeología, May 2003.

# 5 Technical aspects for well construction

To extract water from the groundwater a well needs to be constructed. The four steps during a well construction are:

- Locate where to drill
- Drilling
- Pumping test
- Analysis of the pumping test

Below follow descriptions of these four steps.

## 5.1 Locate where to drill

To choose where to drill in order to find enough water a geologist looks at the geology and the geomorphology within the area. If it is to a private person, for example a farmer, the geologist has to select a spot which is on the person's property. If it is to a village, the well has to be on a reasonable close distance to all the houses so that the pipes do not have to be too long. The first drilling attempt in an area is usually made in the lowest point in the area. Experience has shown that the best chance to find water is in this part of the topology where the best probability to find aquifers in weathered layers are.[25] The aquifer types in the study area. It is also important to take into consideration if there is any old wells close by so the aquifer does not get overloaded.

## 5.2 Drilling

After a drilling place has been located, a machine used for drilling is applied, see figures 5.2a and 5.2b. No cores are taken in this area. With a core it would be possible to get a more precise view of the geology and the characteristics of the rocks. Instead a geological profile is made during the drilling. This is done by a geologist, who supervises and writes down the geology from the soil and rock materials that come up from the drill. The geological profile includes both what kind of soils and rocks there are and can also include if the rock is weathered or has fractures. This is of course difficult when not taking a core, but there are two ways to discover fracture zones in the rock when drilling. During a drilling a fluid or air is forced into the drilling hole and if the fluid or air does not return it has probably disappeared into fractures. The other way to notice fracture zones is when the perforator starts rumbling instead of moving downwards smoothly. The change in resistance indicates that there are fracture zones in the rock. If fracture zones are found in the beginning of the drilling, before the aquifer has been reached, these are injected with for example graphite (which is a kind of clay) to prevent the water

[25] Ing. Ibarra Ruperto, geologist, MIDA, 2003-11-06.

from disappearing into the fractures. After reaching the aquifer the fractures indicate a good water supply.[26]

**Fig. 5.2a**: Photo of a well being drilled. Two well perforators are working with the drilling. Soil, rock material and fluid come up from the drill hole.

**Fig. 5.2b**: Photo of the well perforator. Malin Svendenius is interviewing the geologist Ing. Ibarra Ruperto and Lic. Manuel Ruiz at MIDA.

When drilling it is necessary to drill until the recharge is high enough. On the way down small aquifers can be found, but with a too low recharge why the drilling has to continue until enough water is found. If the well will be used for irrigation the discharge has to be approx. 3 $m^3/h$ and ha and since the normal size of an irrigation area is 3-5 ha in the project area, the approx. discharge needs to be approx 12 $m^3/h$, or 50 g.p.m.[27] The discharge can be lower if the well will be used for domestic water use or for cattle. When the aquifer has been reached the drilling supervising geologist makes an estimation of the maximum discharge that is possible without affecting the aquifer.

When drilling, the hole is made wider in the beginning where the soil and rock are more unstable. Deeper down the diameter is smaller. After the drilling the well is cased with a pipe along the wider part of the hole. The pipe consists of two parts. The upper part of the pipe is impermeable and the lower part is a filter. Around the pipe gravel is placed to stabilise the pipe and the well, to prevent soil and rock material from getting into the well and to facilitate the water transport from the aquifers to the well hole. The filter in the pipe prevents gravel to reach the well hole but allows water from the aquifers to pass through. Deeper down, in the thinner part of the well hole, no pipe or gravel is needed since the rocks are solid.[28]

[26] Ing. Alberto E. Ruiz, geologist, UTP, 2003-10-28
[27] Ing. Roddy Márquez, Co-Director, MIDA, 2003-10-21
[28] Lic. Manuel Ruiz, Irrigation responsible in the project area, 2003-10-29

## 5.3 Pumping test

After a well has been drilled and cased a pumping test is done to calculate the well's capacity. The static level, SL, is measured before the pumping test starts. In an unconfined aquifer the static level is the same as the groundwater table, see figure 5.3. In a well connected to a confined aquifer the static level is usually called piezometric head. But since the term static level is used in the information about the wells in the area, this appellation is applied in this report regardless aquifer type. The dynamic level, DL is the water level when the well is working and the drawdown is the difference between the static and dynamic level, see figure 5.3.

The pumping tests are being performed in slightly different ways depending on the supervisor. In some cases when making a pumping test the pump starts working at the highest possible discharge. After that the discharge is being reduced and then increased every time the drawdown is stabilising. Others start at a low discharge which is increased when the drawdown is stabilised. In both cases the dynamic water level is measured at a certain rate.[29] The duration of the pumping test should be 24 hours for a confined aquifer and 72 for an unconfined aquifer to produce accurate data.[30] But in most cases a very quick test is implemented.

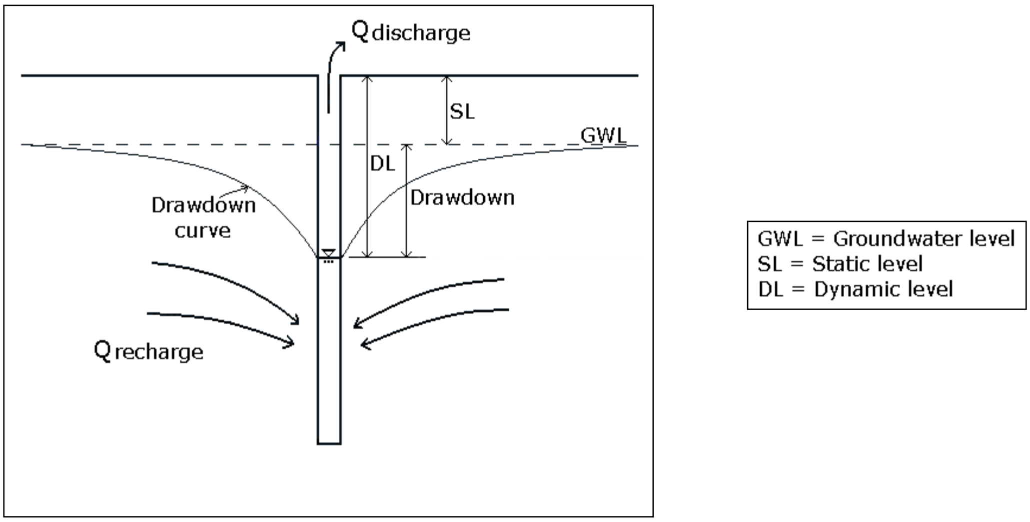


**Fig. 5.3**: Illustration of a vertical cross-section of a well with indications of the different parameters used in a pumping test.

[29] Ing. Roberto Cigarruista, UTP Azuero worked before at IDAAN, 2003-10-27
[30] Fletcher G. Driscoll, *Groundwater and wells*, (St. Paul, Minnesota: John Screens, 2003), 536

## 5.4 Analyses of the pumping test

One aim with the pumping test is to find the highest possible discharge with a constant dynamic water level i.e. how much water the aquifer can supply. A constant dynamic water level is achieved when: Qrecharge = Qdischarge, see figure 5.3. From the pumping test a mean value of the discharge can be calculated, $Q_{mean}$, and this value is an approximate estimation of how much water the aquifer can supply, maintaining a constant dynamic level. A more correct estimation is made by using more advanced calculations that gives a more precise value of the highest possible discharge. This value is called $Q_{balance}$ or $Q_{equilibrium}$.

# 6 Analysis

## 6.1 Database

In Sweden there exists a database with well information called the well archives. The swedish authority 'The Geological Survey of Sweden' has stored information from well drillings and groundwater investigations in these archives. According to the swedish law it is obligated for the well owners to give information of the wells to be stored in the archives of wells. The information in the archives of wells is easy to get access to through internet.[31] Today there are no such archives of wells in Panama. One of the objectives with this study is to start making a similar database in Panama.

In order to start making this database, information of 57 wells was collected from the four different authorities; IDAAN, MINSA, MIDA and ANAM; that are in charge of the wells in the area around the Pesé stream. All this information has been put together in a database to give an overview of the wells and simplify the study of the groundwater. This database is attached in Appendix B. The parameters in the database are:

- whether the well is in use or not
- age
- location
- depth and elevation
- drilling information
- pump-test parameters
- working discharge (Qneeded)
- water use information
- if there exists a geological profile

Some wells have very little information and most of the wells have some lack of information. But the idea is that this kind of database should function as a model for future compilation of well information. In the future better documentation of the wells needs to be done and all the parameters should be registered in the database. In order to draw conclusions about the groundwater and the aquifers all the data about the wells need to be gathered in one place.

There exists almost no documentation of the wells where very little or no water at all was found. Some of these wells have been approximately located together with personal at MIDA and land owners, see figure 6.1. Oral information and the locations of these wells have then been documented in the database. There are probably several more non successful well drillings that have been missed because of lack of information and bad documentation. This affects the analyses in chapter 6.2, Well data. The conclusions of the aquifers would be more accurate if all the wells drilled in the area had been documented.

[31] The Geological Survey of Sweden, <http://www.sgu.se>, (2004-04-19)

All the wells have been given a number between 1 and 57 to simplify the handling of data throughout this report.

**Fig 6.1**: Photo of location of well 42. Malin Svendenius; Manuel Ruiz, MIDA; and Miguel Coba, landowner.

## 6.2 Well data

### 6.2.1 Owners

The map of the area was digitalized and all the wells were plotted by using the GIS-programs ArcInfo and ArcView. Figure 6.2.1a shows the 57 wells and which authority that is in charge of the wells. In Appendix B with the database the community, owner or industry that is in charge of the well can be seen.

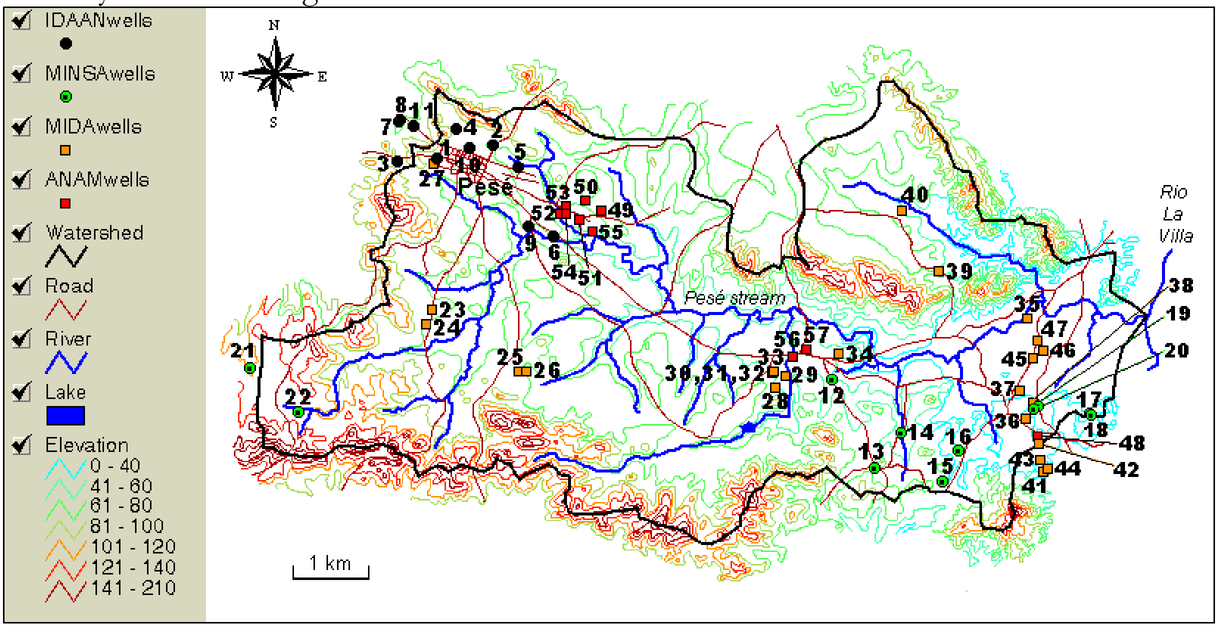


**Fig 6.2.1a**: Map of the wells showing the allotted numbers and the authorities that are in charge of the different wells.

### 6.2.2 Discharge

The wells have different capacities and figure 6.2.2a shows the different discharges from the wells. The discharges used for this figure are presented in Appendix B. For those wells where a pump-test has been performed, the discharge, measured and calculated as Qmean or Qbalance, is shown on the map. If there has not been a pump-test, the working discharge for the well, called Qneeded in Appendices B1:4 and B2:4, is used. If the well does not have a pump-test and is not in use the approximate discharge estimated during drilling is applied.

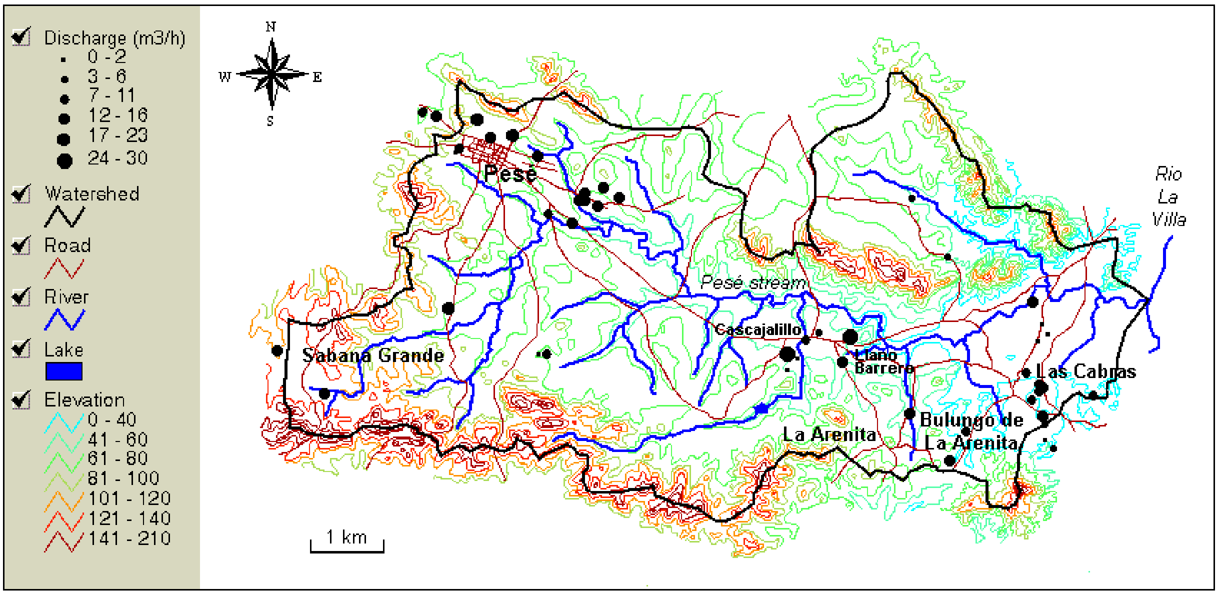


**Fig 6.2.2a**: Map of the different discharges of the wells.

**Table 6.2.2:** The evaluation of the discharges shown in figure 6.2.2

| Discharge ($m^3/h$) | Evaluation of the discharge | Sufficiency |
|---|---|---|
| 0-2 | No discharge | |
| 3-6 | Very low discharge | Not sufficient discharge |
| 7-11 | Low discharge | Sufficient for domestic use and cattle |
| 12-16 | Good discharge | Sufficient for irrigation of an area of 3-5 ha |
| 17-23 | Very good discharge | |
| 24-30 | Excellent discharge | |

The evaluations of the discharges in table 6.2.2 are general guiding principles in the project area. The term *sufficiency* signifies that the discharge is high enough to be economically useful. A well can have a lower discharge than the guiding principles and still be in use. For example if a well is drilled in order to be used for irrigation and the discharge is not sufficient, the well can still be utilized, but the irrigation area has to be reduced.

The map indicates that the wells with the best discharges in the project area are situated around Cascajalillo, Llano Barrero and Pesé. In Pesé almost all of the wells belong to IDAAN and they have low to good discharges. Southeast of Pesé are several wells that ANAM is responsible for and they are used for industrial purposes such as pork breeding and alcohol production. Also these wells have low to good discharges. In Las Cabras the discharges of the wells are quite low, most of the wells in that area do not have sufficient discharge for irrigation, which is 12 $m^3/h$ for an area of 3-5 ha. The two wells in Cascajalillo and Llano Barrero are wells with excellent discharges. But it is important to be aware of that very close to them are several wells with very low or no discharge. The well with excellent discharge in Cascajalillo is situated approx. 20 m from wells with no discharge at all. In Sabana Grande and the surrounding area are a few scattered wells and some of them have good discharges. In Arenita and Bulungo de La Arenita are three wells for domestic use, belonging to MINSA. Two of these wells have good discharges and one of them has low discharge, but still sufficient for domestic use.

**6.2.2.1 Interpolation of the discharges in the study area**

By using the discharges explained above, an interpolation of the study area has been made, see figure 6.2.2b. This gives an estimated picture of where there could be aquifers in the area. Unfortunately figure 6.2.2b is not a sufficient tool to decide where to drill, since the interpolation is based on few reference points and the interpolation map does not refer to what kind of geology and thus where there are weathered zones in the area. The interpolation in figure 6.2.2b is only intended to the discharges from wells.

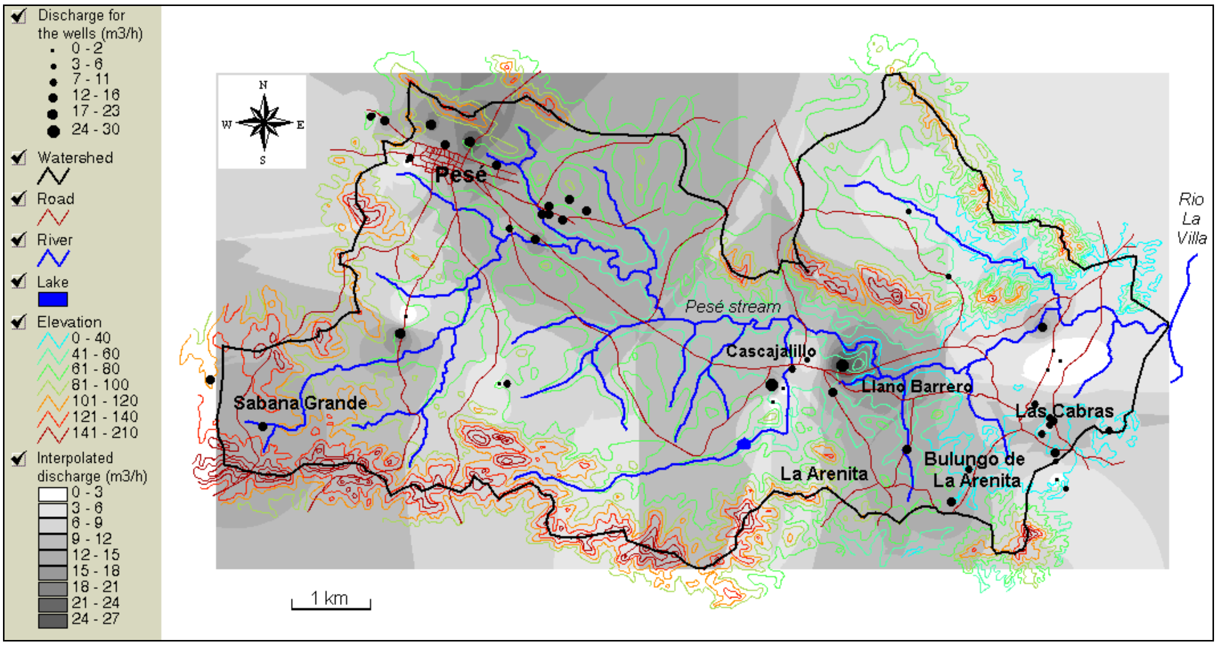

**Fig. 6.2.2b**: Map of the interpolation of the discharges for the wells.

According to figure 6.2.2b the areas with the estimated aquifers are located just north of Pesé and around Llano Barrero and down to Bulungo de La Arenita. There could also be good discharges in Sabana Grande and southeast of Pesé.

## 6.2.3 Geological profiles and cross-sections

In order to get a better estimation of where there are aquifers it is necessary to study the geology since some geological layers have better aquifer characteristics than others.

Only 15 of the wells in the watershed of stream Pesé have geology information that has been documented during the drilling of the wells and kept by the departments. The geology is presented as geological profiles, see chapter 5.2, Drilling. In figure 6.2.3a the wells that have geological profiles are indicated with a black spot in the middle of the circle. Of the 15 profiles that exist are 8 made by IDAAN and 7 by MIDA. All these geological profiles are accessible in Appendix C and an example of a geological profile is shown in figure 6.2.3b.

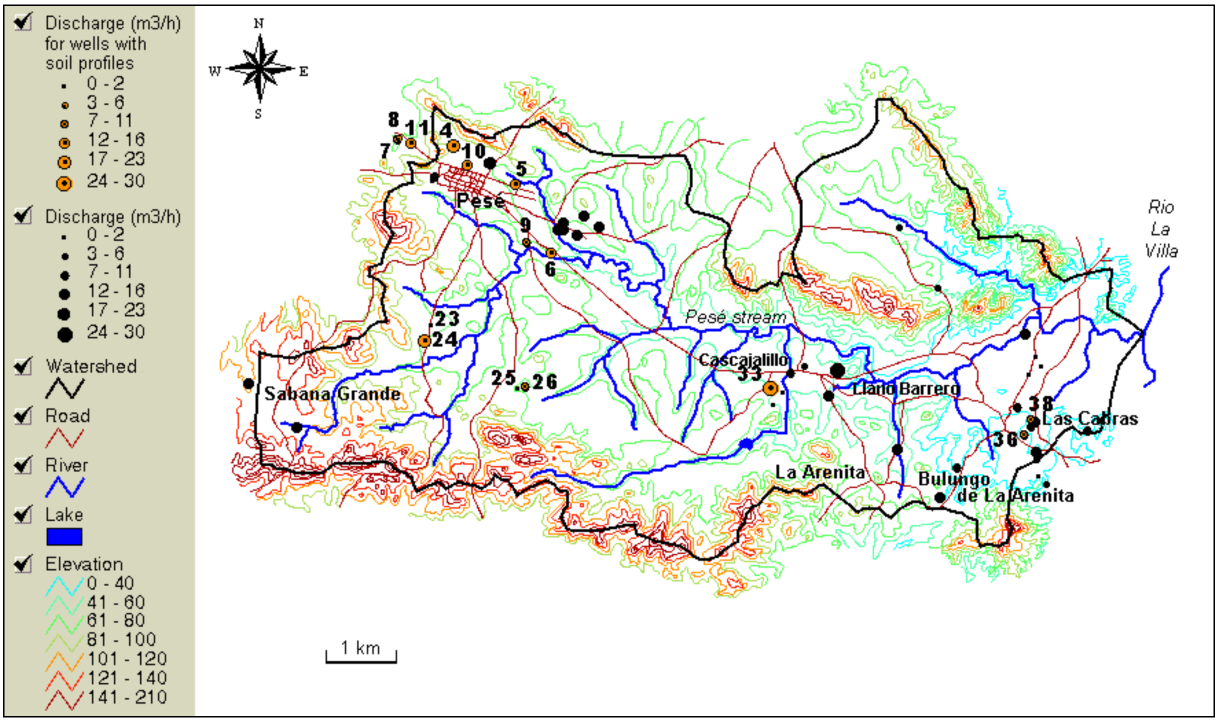


**Fig. 6.2.3a**: Map showing which wells that have geological profiles. These have black spots in the middle and their well number is written on the side. The map also shows the different discharges of all the wells.

The geological profiles give approximate descriptions of the geology in the wells. In all the geological profiles the top layer, that is clay in the whole watershed, is visible. The weathered rock layer has often the same lithology as the underlying rock. When measurements of the static and dynamic levels have been done in a pumping test they are also marked in the geological profiles as SL, Static Level and DL, Dynamic Level. In the geological profiles of the IDAAN-wells there is no documentation of where water was found during the drilling, but in the geological profiles of the MIDA-wells there are better descriptions of where water has been found. These are visible in Appendix C2. Most of the time water has been found in the weathered rock layer and sometimes in the fresh rock and/or fracture zones. Below follow geological descriptions made from the geological profiles. They describe the geology and the aquifer characteristics for local areas in the Pesé stream area.

### 6.2.3.1 Sabana Grande

In Sabana Grande there is one well with a very good discharge, well nr 24, see figure 6.2.3b, where some water has been found in the weathered rock and a lot of water further down in the weathered rock and in the fresh rock, which is tuff. The static level is placed in the weathered rock layer which indicates that the aquifer is unconfined, see chapter 4.4.3, and it has a good recovery capacity since the dynamic level is close to the static level.

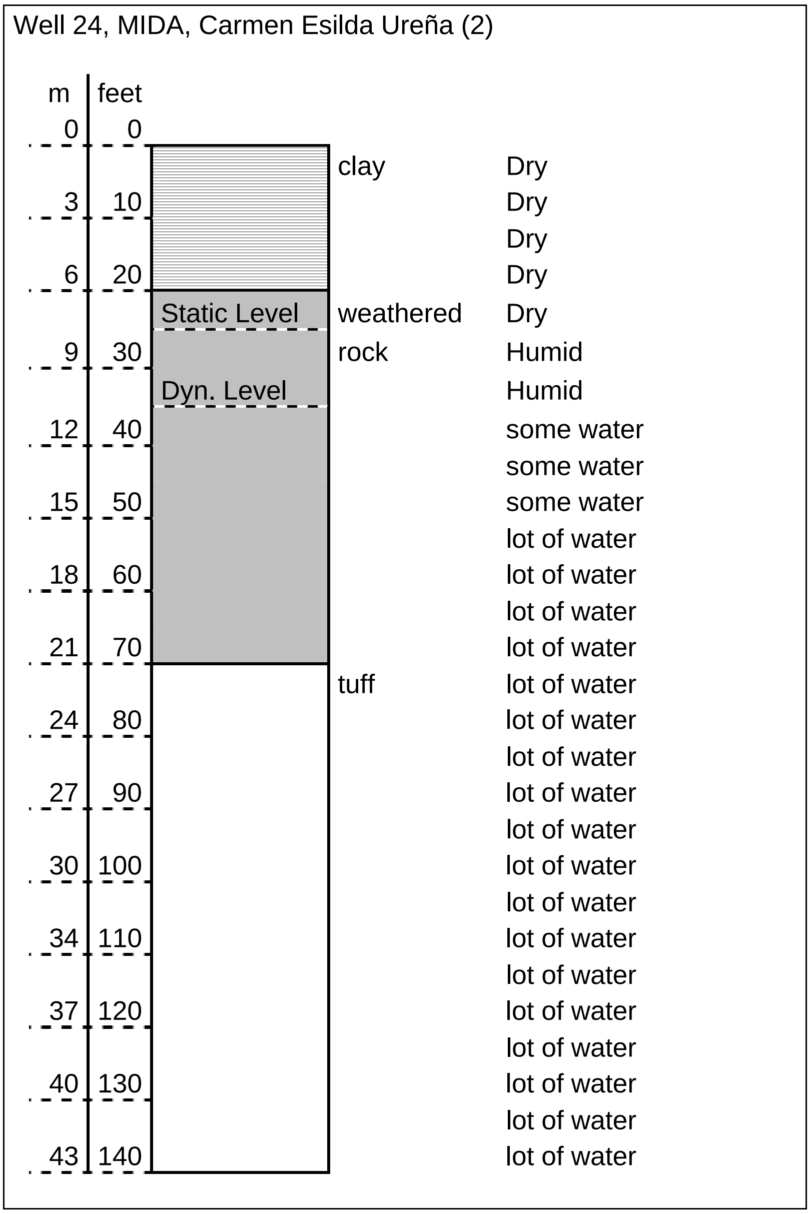


**Fig. 6.2.3b**: Illustration of the geological profile of well 24 in Sabana Grande.

About 400 meter from well 24 is another well, well nr 23, which collapsed and does not have any discharge at all. The geology of this well is compacted basalt, see Appendix C2:1. Weathered rock and tuff have better aquifer capacity than compacted basalt and where there are weathered rock and tuff there are chances to find water. However it is not possible to say exactly where there is tuff and where there is compacted basalt in this area since there are only two profiles.

Further to the east in the outskirt of Sabana Grande there are two geological profiles made for well 25 and 26, see Appendix C2:2. The geological profile to well 25 shows a very thin weathered rock layer on top of compacted andesite. The well has almost no discharge. Probably because the weathered layer is not thick enough to store sufficient amount of water and also because the compacted andesite does not contain any fracture zones. Well nr 26 is situated about 100 m to the east from well nr 25. The geological profile to well 26 contains of tuff, but the well still has a low discharge. The static level in well 26 is placed in the clay layer on top of the tuff. This indicates that the aquifer is confined, see chapter 4.3.3, Aquifers, and the dynamic level is placed very low down in the tuff layer which shows that the drawdown is large and the recovery capacity is little. Even though the geology contains of tuff there is no guaranty for a good discharge. There is no weathered layer in this geological profile and that might contribute to less leading capacity of the geology compared to the aquifer that gives water supply to well 24.

### 6.2.3.2 Las Cabras

Two of the wells in Las Cabras with the allotted numbers 36 and 38 have geology-information, see figure 6.2.3c. By using the information in these geological profiles, see Appendix C2:3 and C2:4, a cross section for the geology between the wells has been drawn, see figure 6.2.3c. This cross-section is a rough description of the geology, with the estimation that the geology is the same between the wells. The geology contains mainly of sandstone which has both coarser and finer grains consisting of calcite, chloride, quartz and hematite. This type of sandstone in the Pesé stream area has a low permeability, see chapter 4.3.1.2, but since the sandstone is more or less weathered and fractured it has some aquifer capacity.

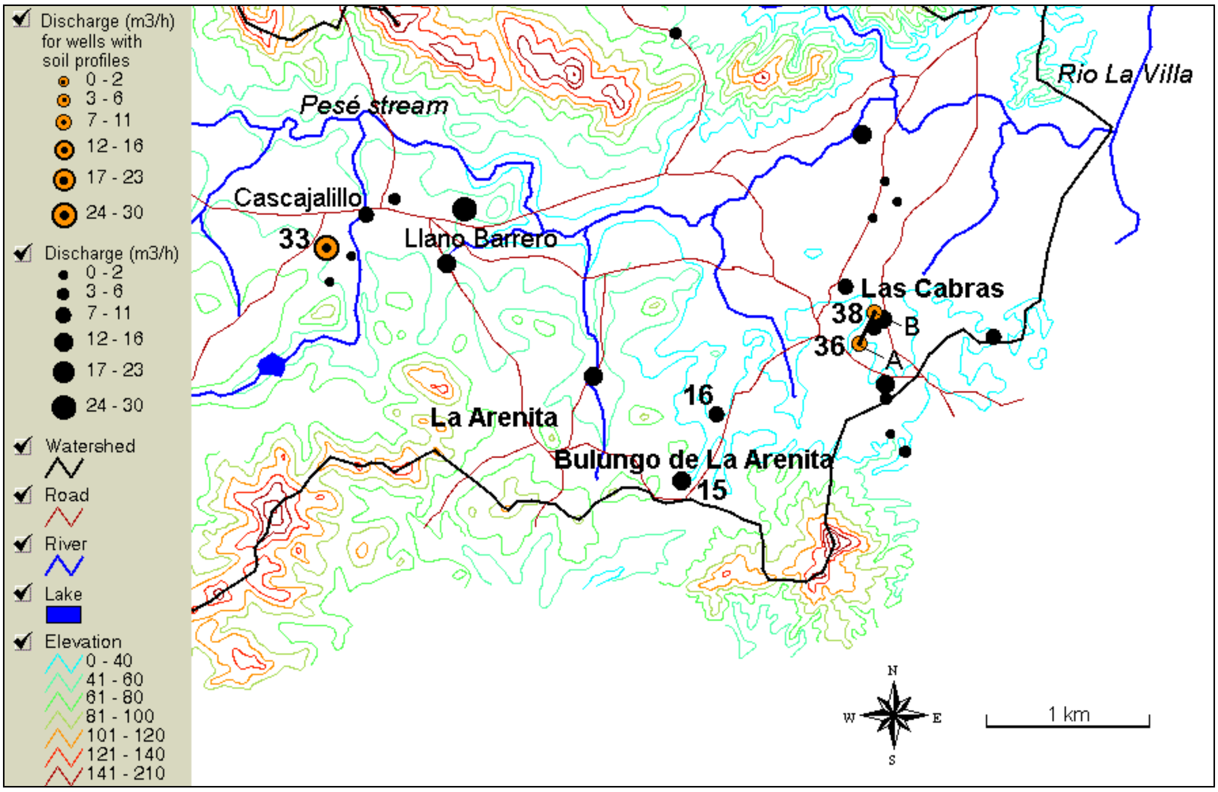


**Fig. 6.2.3c**: Map of the wells in Las Cabras, Cascajalillo, Llano Barrero and Bulungo de La Arenita.

In view of the fact that the sandstone in Las Cabras contains of grains with different sizes water can also be transported through the pores between the grains in some places. In well 36 a lot of water was found around 8 meters down from the ground level. The sandstone in this well is more weathered and fractured than in well 38, where a lot of water was found deeper down at around 18 meters. The discharges of the wells are the same, 9 $m^3/h$, which indicates that it probably is the same aquifer. This discharge is low and one of these wells can only supply maximum 3 ha of irrigation area. The static level occurs in the sandstone in both of the wells so the aquifer has unconfined characteristics.

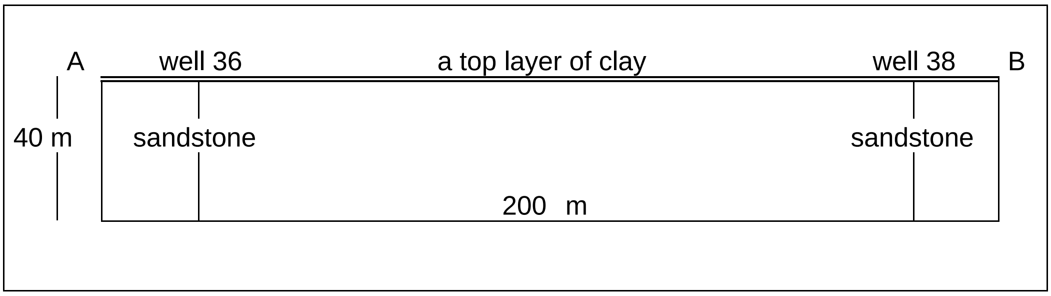


**Fig. 6.2.3d**: Illustration of a cross-section in Las Cabras.

### 6.2.3.3 Cascajalillo and Llano Barrero

There is only one well in this area that has geology information, well 33, see figure 6.2.3c and Appendix C2:3. This well has one of the best discharges in the Pesé stream area. The geology here consists of tuff and andesite and a lot of water has been found from around 9 m down. This aquifer seems to have confined characteristics since the static level occurs in the clay layer. However it is difficult to draw any conclusions about the aquifers in this area since several wells in the vicinity of well 33 do not have any discharge at all and there does not exist any more geology information. The geology probably changes suddenly here.

### 6.2.3.4 Bulungo de La Arenita

There are no geological profiles to the wells 15 and 16 in Bulungo de La Arenita but outcrops in the vicinity of the wells were studied while visiting the area. The geology in the wells is probably the same as the outcrops show. The outcrop close to well 15 shows weathered tuff, see figure 4.3.1d and this well has a good discharge. The outcrop close to well 16 shows silicificated volcanic rock, see figure 6.2.3e. This well has a low discharge.

**Fig. 6.2.3e**: Photo of outcrop of silicificated volcanic rock close to well 16 in Bulungo de La Arenita.

### 6.2.3.5 Village Pesé

There exists geology information for several of the wells in Pesé that IDAAN is in charge of, see fig 6.2.3f and Appendix C1. The depths of the functioning wells of IDAAN are usually around 50 - 60 meters. By using the information from the geological profiles two cross-sections have been done. The cross-section from point C to D, including wells 4, 10 and 9, see fig 6.2.3g shows that the geology differs a lot. Wells 4 and 10 have good discharges which indicate that there are aquifers in the limestone and the weathered andesite. Since there is no information of any fracture-zones in the compacted andesite the aquifer is probably situated in the weathered layer. Well 9, which consists of tuff, has a low discharge, but sufficient for domestic use.
In the cross-section from point E to F, the one for wells 11, 10 and 5, see fig 6.2.3h, the geology seems to be almost the same. All of these wells have good discharges. The aquifers are located in the weathered andesite and/or in the fresh andesite. When water is found in the fresh andesite it is probably transported through fracture zones in the fresh rock.

In cross-section E to F the geology is almost the same, but in the other cross-section it varies. This study is not enough to define more precisely how the geology is in Pesé and where it is most possible to find water. The geological profiles of the wells look different, but there are some similar characteristics. Studies of the geological profiles of the IDAAN wells in Pesé show that there are mainly three types of geology compositions in the wells in Pesé:

- The most common is a compacted layer of andesite in the bottom of the well. This layer is not weathered and could be considered as fresh rock. Above the fresh rock is usually a weathered layer. The depth of the weathered layer differs and sometimes there are thinner middle layers of fresh rock. The fresh rock starts at 24-42 meters down. According to MIDA the recharge to the wells does not increase with deeper depth than this.[32] The mean value of the depth of the MIDA wells is around 140 feet which is 43 meters. This emphasizes the theory that the aquifers are in the weathered layer.

- Two geological profiles (well 8 and 9) are mainly composed of tuff.

- One geological profile (well 4) is composed of limestone. This well has the highest discharge of the wells in Pesé village.

[32] Ing. Roddy Marquez, Co-Director, MIDA, 2003-10-20

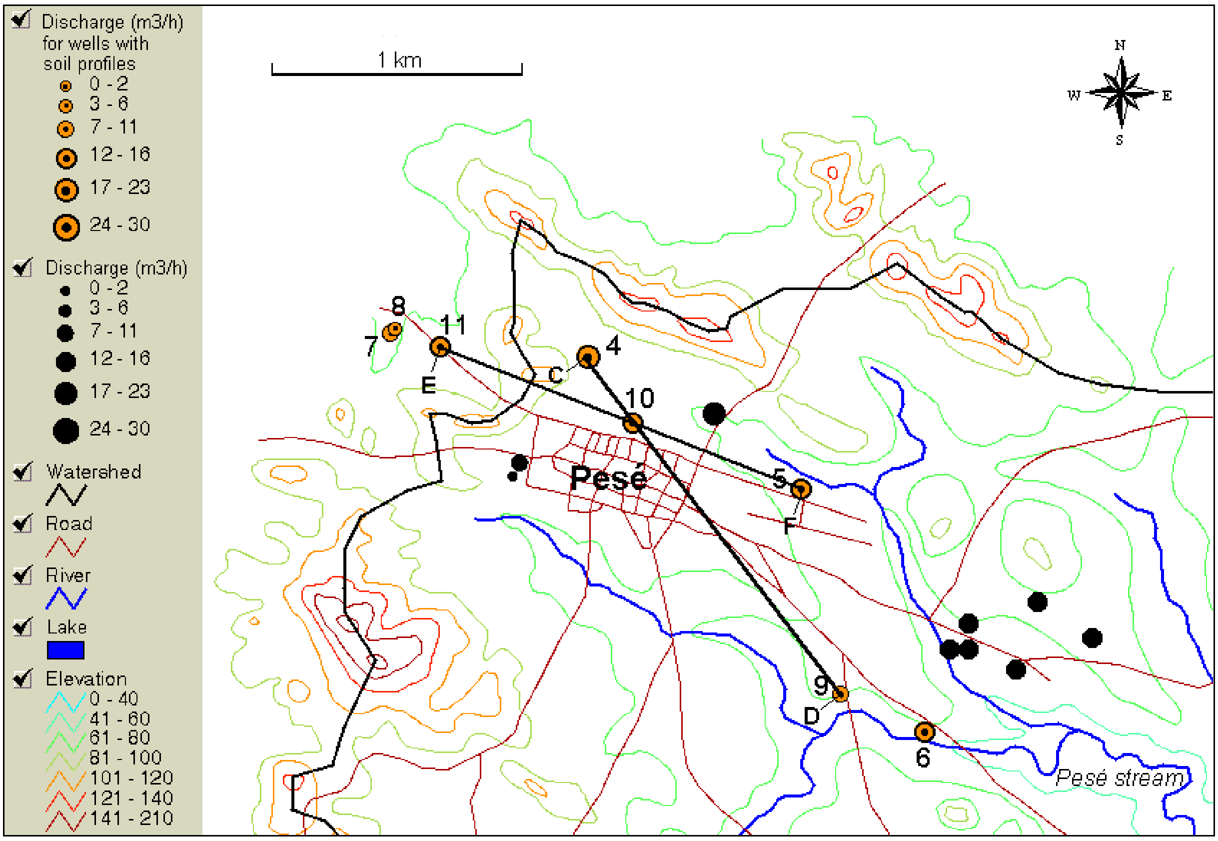


**Fig 6.2.3f**: Map of the wells in the area around village Pesé.

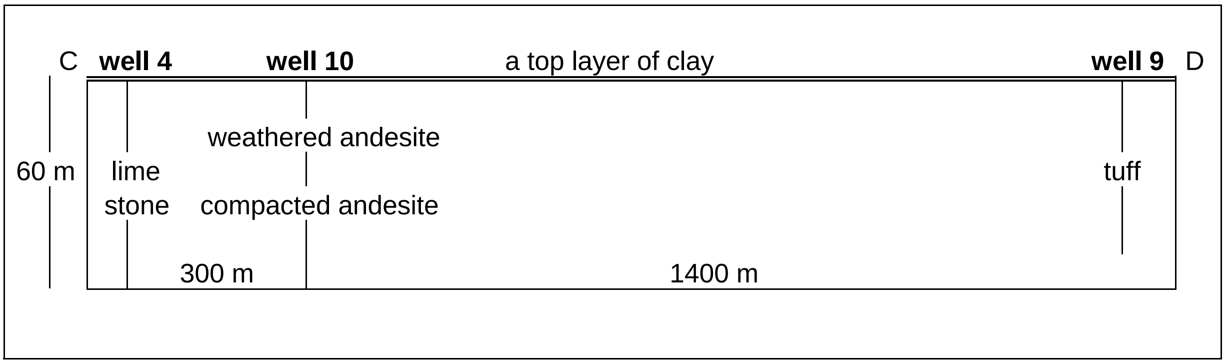


**Fig 6.2.3g**: Illustration of cross-section for wells 4, 10 and 9 in Pesé.

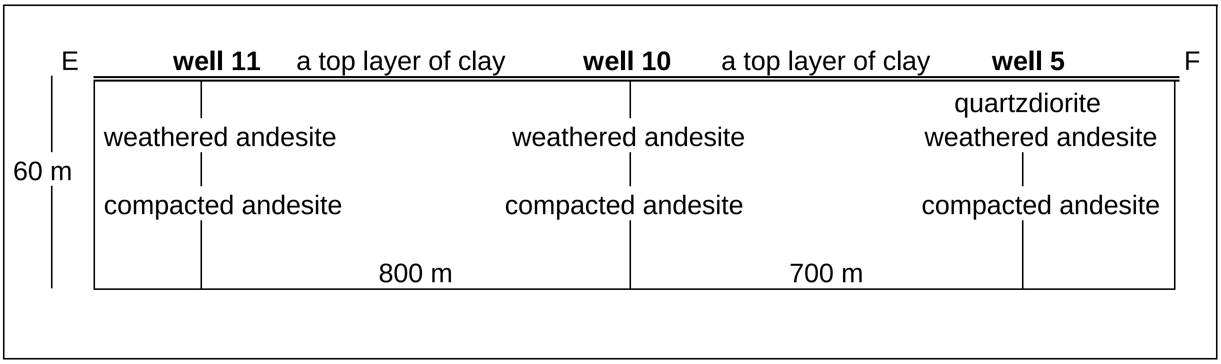


**Fig 6.2.3h**: Illustration of cross-section for wells 11, 10 and 5 in Pesé.

### 6.2.4 Measurements

The measurements of the static and dynamic levels in the wells were made during the rain-period in the end of October. Since the static and dynamic levels differ depending on season, a comparison of the values is only interesting if all of them are taken in a short time period. The measurements are assembled in Appendix D and include the measurements of the levels, the working discharge and exact dates. When the dynamic level of a well was measured the length of the time since the well started working, which is called working time, was noted. If the well was resting during the measurement the length of the time since the well stopped working, i.e. the standby time, was noted. All the static levels and dynamic levels for the functioning wells of IDAAN were measured and the working time and standby time were noted, see table 6.2.4.
Since the wells of MINSA do not have exact working schedules and due to lack of time, all the static and dynamic levels could not be measured. All the MIDA wells are only working in the dry period, so it was only possible to measure the static levels in these wells since the measurements were made in the rain period. Only one well under the responsibility of ANAM could be measured. Figure 6.2.4a shows the authors measuring the water level in one of the wells in Pesé and figure 6.2.4b shows a well operator at IDAAN helping with the measurements of another well in Pesé.

**Fig 6.2.4a**: Photo of measurement of the water level in well 8 (IDAAN B9) in Pesé by Lena Sjunnesson and Malin Svendenius.

**Fig. 6.2.4b**: Photo of well operator Luis Valdez, IDAAN, taking out the plastic tube in well 1 (IDAAN B1) in Pesé so that measurements can be done.

### 6.2.4.1 Interpolation with the measured static and dynamic levels in the area around village Pesé

Since complete measurements of all the functioning wells of IDAAN in Pesé were performed the area in and just around village Pesé was selected in order to make an interpolation of the drawdown, see figure 6.2.4c. The interpolation is made in ArcView by using following measure data:

- Static level
- Dynamic level
- Working discharge

The drawdown is as mentioned in chapter 5.3, Pumping test, the static level minus the dynamic level. Table 6.2.4 shows the measurements. In figure 6.2.4c the areas that are brighter have lower drawdowns than the darker areas. If the drawdown is low the aquifer has a good recovery capacity and the recharge from the aquifer is high. Figure 6.2.4c shows that the estimated aquifers are situated northeast and southeast of Pesé. Almost the same conclusion was taken when an interpolation for the discharges was made for the whole watershed in chapter 6.2.2.1. However it is not secure that an area with low drawdown according to the interpolation in figure 6.2.4c has a good aquifer capacity in reality since the geology varies and may not be the same as the geology in the wells, see chapter 6.2.3.5.

**Table 6.2.4:** Static and dynamic level measurements of the wells of IDAAN in Pesé.

| The wells of IDAAN in Pesé | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Well | IDAAN | In use | Static level | | Dynamic level | | | Drawdown |
| no | no | | stand by time | level | working time | level | discharge | |
| | | (x=yes) | (h) | (m) | (h) | (m) | ($m^3$/h) | (m) |
| 1 | B1 | x | 18 | 6,3 | 25 h 30 min. | 8,0 | 7,3 | 1,7 |
| 2 | B3 | x | 2 h 45 min. | 7 | 24 | 8,7 | 12,7 | 1,7 |
| 3 | B4 | no | | 5,2 | | | | |
| 4 | B5 | no | | 9,8 | | | | |
| 5 | B6 | x | 11 | 1,4 | 8 | 2,9 | 18,9 | 1,5 |
| 6 | B7 | x | 17 h 30 min. | 3,7 | 26 | 6,2 | 9,1 | 2,5 |
| 7 | B8 | no | | 2,7 | | | | |
| 8 | B9 | x | 2 h 30 min. | 3,2 | 24 | 6,0 | 7,3 | 2,8 |
| 9 | B10 | x | 11 h 30 min. | 1,1 | 8 h 30 min. | 2,6 | 9,1 | 1,5 |

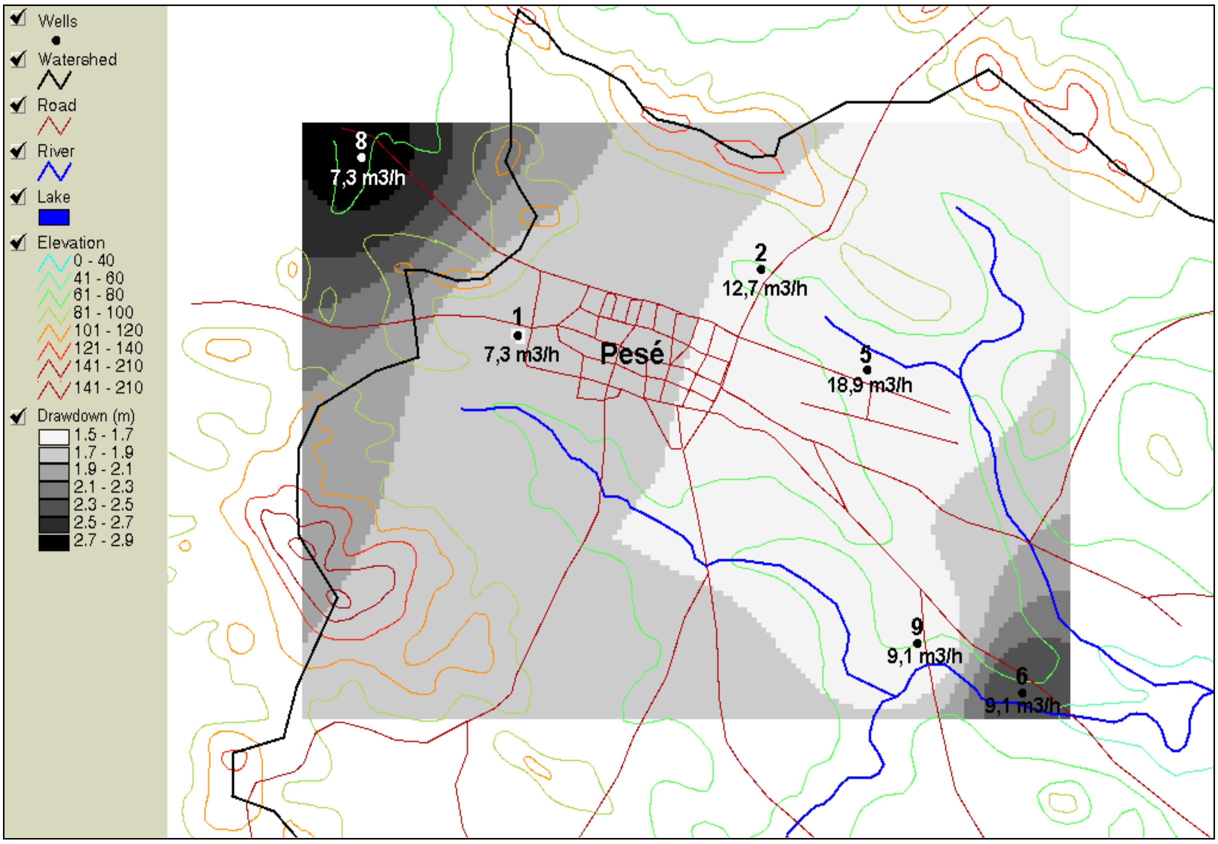


**Fig. 6.2.4c**: Map of interpolation of the drawdowns in village Pesé. The working discharges for the wells are written just below the wells.

## 6.3 Pattern of the groundwater flow

Recharge and discharge areas indicate the in- and outflow of the groundwater. Recharge areas are generally places of higher elevation where the precipitation infiltrates into the soil and through porous material or through cracks in the rocks to the aquifers. Once the water enters the geological profile, the groundwater is transported towards the discharge areas. The discharge areas are places where the water is transported back to the surface. These discharge areas are usually found in low-lying valley locations such as wetlands, rivers, lakes and streams. To find out if a stream is a recharge or discharge area the water flow in the stream during dry periods, when there is no precipitation or runoff, can be studied. This is called the basic water flow. If there is a basic water flow, the stream is mainly a discharge area.

### 6.3.1 Pesé stream

Even during the dry periods there is a basic water flow in the Pesé stream. The stream does not dry out when there is no precipitation. This means that the stream is fed with water from groundwater reservoirs and the stream is considered as a discharge area while the areas higher up in the watershed are considered as recharge areas, see figure 6.3.1.

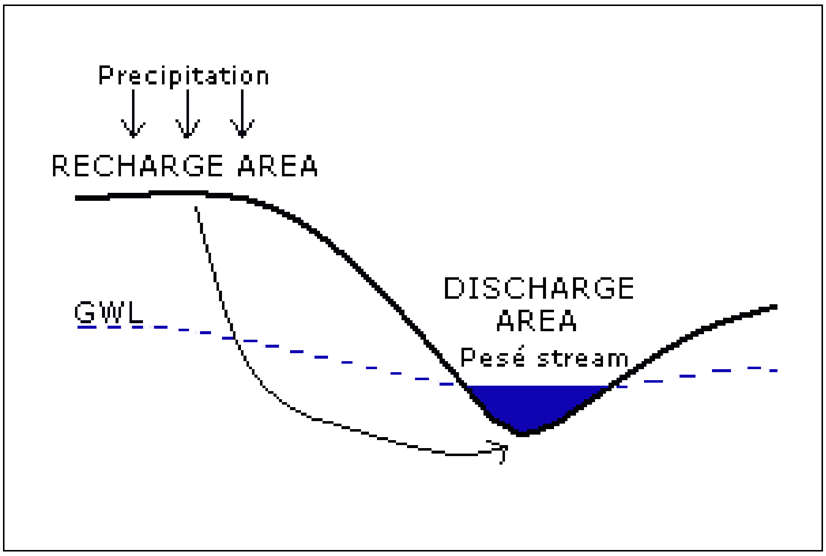


**Fig 6.3.1**: Illustration of the recharge and discharge areas in Pesé stream watershed.

## 6.4 Water use

### 6.4.1 Water use today

The water use in the project area is shown in table 6.4.1. In the table four water supply areas are separated into the responsibility areas of the four authorities IDAAN, MINSA, MIDA and ANAM. The table shows that domestic water use is more than half of the total groundwater consumption in the watershed while agricultural and industrial use is between one fourth and one fifth each.

**Table 6.4.1:** Water use in Pesé, on the countryside, for agriculture, and for factories per season and totally.

| Water use | | Wet season | Dry season | Total | Percent |
|---|---|---|---|---|---|
| | | (m3/season) | (m3/season) | (m3/per year) | (%) |
| IDAAN, Domestic | Pesé | 160160 | 160160 | 320320 | 33% |
| MINSA, Domestic | Countryside | 108624 | 108624 | 217248 | 22% |
| MIDA, Irrigation | Agriculture | 0 | 218936 | 218936 | 22% |
| ANAM, Production | Industries | 110192 | 110881 | 221073 | 23% |
| | Total | 597912 | 379665 | 977577 | 100% |

### 6.4.2 Water use calculations

To estimate the water use in Pesé calculations were made from the discharge and the daily working period for the wells of IDAAN, see Appendix E:1. The total water use in Pesé is approx. 321 000 $m^3$. Since the population of Pesé is about 2600 person[33] water used by one person in one year is 125 $m^3$. The total amount of households in the district Pesé was, year 2000, 3286 households and the total amount of people in the district Pesé was 12 470[34]. This shows that the mean value of a household is about 4 people. Since the number of households in the small communities in the project area is known, an estimation of the water consumption in the countryside could be made, see Appendix E:2. The total domestic water use in the countryside in the project area is calculated to be approx. 217 000 $m^3$ water per year.

To approximate the water used for irrigation information from a study made by Tahal[35] for MIDA is used. According to the study the quantity of water used for irrigation is 46 $m^3$/ha and day. The irrigation area for each farmer is known and the irrigation period is 182 days[36], i.e. the summer. From this the total water consumption is calculated to be approx. 219 000 $m^3$ per year, see Appendix E:2.

[33] Contraloría General de la República de Panamá, Censos Nacionales Población y Vivienda 2000, Resultados Finales Básicos: Totales del País, Recieved from IDAAN.
[34] Dirección de Estadística y Censo – Información Estadística al Servicio del País, *Algunos Indicadores socio-demográficos de la república según provincia y distrito: Censos de 1990 y 2000*
[35] Tahal Consulting Engineers LTD, *Proyecto de Riego del Arco Seco, Informe Final – Hidrogeología*, May 2003
[36] Ibid.

The three industries in the area, two alcohol distillery factories and one pork breeding farm, use together approx. 221 000 $m^3$ groundwater per year. This is estimated from the amount of water the industries use per day. One industry, Alcoholes del Istmo S.A., uses more water during the wet season when the water recharge to the well is larger, see Appendix E:3.

The total groundwater consumption during a year for the whole project area is almost one million cubic metres. Only the discharge from wells that are documented by the authorities is considered, discharge from private wells is not in the calculations. Interviews with local people and authorities give the information that it probably do not exist many private wells with a discharge that would change the calculations very much.

### 6.4.3 Water use changes

In the last years, with start 1999, MIDA started a project to help farmers in the area to drill wells for irrigation during the dry periods. This has raised the water consumption in the area with more than twenty percents. Because the population in the project area is constantly growing, the water consumption has increased, but the growing rate is small and does not affect the outtake from the wells very much. In the future the irrigation areas might increase, but probably not. Today five farmers in the area use irrigation. More farmers would like to use groundwater for irrigation but drilling attempts have been made in several parts of the area without finding enough water.

## 6.5 Water supply

To estimate how much water that is available from the aquifers the values of the basic water flow in the river/stream is reviewed in the dry seasons after years with lower precipitation during the rain season than the average year. The basic water flow is, as mentioned in chapter 6.3, Pattern of the groundwater flow, the outflow from the aquifers during the dry period and since it hardly rains during this season it does not include runoff or rainwater. To get the best estimation, the basic outflow in the Pesé stream should be considered. It does, however, probably not exist any data of such measurements why instead the basic flow in Atalayita, Rio La Villa, see figure 4.2b, is reviewed and then extrapolated into the Pesé stream area. The flow in the Atalayita station is the recharge from approx. 750 $km^2$ of the watershed of Rio La Villa, if making the estimation that the groundwater has approx. the same boundaries as the watershed.

Five years with the lowest precipitation, between the years 1972 and 1996, were chosen. These years are 1976, 1983, 1987, 1991 and 1992, see Appendix F, table 1. The discharge in Atalayita from the four driest following months (January-April) after the rain period was selected. For example, if the precipitation was low year 1976, the discharge from the beginning of 1977 was taken, see Appendix F, table 2. An average of these months was calculated and it was estimated to be the year average outflow from the aquifers per month, called Q in Appendix F, table 3; to the river in this part of the Rio La Villa watershed. The total volume of water from the aquifers in this area was calculated and this was divided with the area, 750 $km^2$, to get a constant that was multiplied with the area of Pesé, which is approx. 44.9 $km^2$.

The calculations show that the average outflow from the aquifers for a dry year is approx. 10.6 million $m^3$. It also shows that the year with the lowest discharge does not have to provide the river with the lowest discharge from the aquifers.

## 6.6 Water quality

### 6.6.1 Surface water

The environmental authority ANAM has made a research of the surface water quality in the Rio La Villa Watershed.[37] This research was made between October 2001 and December 2002. All the following data about the surface water in Pesé stream watershed has been taken from this report

Water samples were taken and analysed in 12 places in the watershed once during the dry season and once during the rain season by ANAM. One of these places is situated in the project area. Water samples were taken in the Pesé stream, in the area of Las Cabras, see figure 6.6.1. The different water chemistry analyses can be seen in table 6.6.1a together with the results from the Pesé stream. Below table 6.6.1a follow an explanation of the different water chemistry analyses.

**Table 6.6.1a**: Results from the chemistry analyses of the water samples from the Pesé stream.

| Season | $BOD_5$ | Solid suspended matter | Nitrogen total | Phosphate | Oil and grease | Chlorine pesticides | Organic phosphorous pesticides | Copper |
|---|---|---|---|---|---|---|---|---|
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (µg/L) | (µg/L) | (mg/L) |
| Dry | <2 | 7 | 0,62 | 0,399 | <0,5 | <1 | <1 | <0,01 |
| Rain | 11 | 206 | 3,43 | 0,47 | <0,5 | <1 | <1 | <0,01 |

| Season | Iron | Fecal Coliformes | pH | Temperature | Electrical Conductivity | Dissolved solids | Dissolved oxygen |
|---|---|---|---|---|---|---|---|
| | (mg/L) | (CFU/100ml) | | (°C) | (µS/cm) | (mg/L) | (mg/L) |
| Dry | <0,05 | 220 | 7,7 | 28,3 | 550 | 350 | 5,3 |
| Rain | 4,9 | 0,00034 | 7,09 | 27,5 | 175 | - | 4 |

[37] Autoridad Nacional del Ambiente, ANAM, *Proyecto Piloto de Monitoreo de la Calidad del Agua de la Cuenca del Río La Villa, Provincias de Herrera y Los Santos y su aplicación en las Principales Cuencas Hidrográficas de Panamá*

The different parameters that were analyzed are:
**$BOD_5$:** BOD signifies Biochemical Oxygen Demand and $BOD_5$ is the amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter.[38]
**Solid suspended matter**: Indicates how many solid suspended particles there are in the water.
**Nitrogen (N), total**: The total amount nitrogen in different forms where the two most common forms of nitrogen are nitrite ($NO^{2-}$) and nitrate ($NO^{3-}$). These are both important nutritive substances and can in a too big quantity contribute to eutrophication.
**Phosphate:** The most common form of phosphate (P) is phosphorous ($PO4^{3-}$). Phosphorous is, like nitrite and nitrate, an important nutritive substance and can contribute to eutrophication if the quantity is too big.
**Oil and grease:** Indicates how much oil and grease there is in the water.
**Chlorine pesticides:** Pesticides with chlorine ($Cl^-$).
**Organic phosphorous pesticides:** Pesticides with organic phosphorous.
**Copper and Iron:** Copper (Cu) and Iron (Fe) are two heavy metals. They mainly derive from the bedrock.
**Fecal coliformes:** Bacteria
**pH:** pH is the measurement of acidity or alkalinity in aqueous solutions. It can have the values from 0 to 14 where pH 7 is neutral.
**Temperature:** Some parameters, for example pH, are dependent on the temperature.
**Electrical Conductivity:** Electrical conductivity estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water.[39]
**Dissolved solids:** The total dissolved solids content in a volume of water is a measure of the sum of the concentrations of the dissolved major ions. The total and individual concentrations of the constituents vary by location and seasonally due to natural and human induced influences on watersheds.[40]
**Dissolved oxygen:** Dissolved oxygen analysis measures the amount of gaseous oxygen ($O_2$) dissolved in an aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis.[41]

To get a value of the water quality all these results were considered by ANAM by three norms; the Chilean norm, the Brazilian norm and the European Union norm. This means that instead of taking the exact value of the chemical parameters into consideration, the values are put together and evaluated from a norm. The Chilean norm treats the suitability of the water concerning aspects from industrial use to drinking water for animals and irrigation; the Brazilian norm treats the suitability of water concerning aspects from less demanding usages to domestic water supply; and the European norm evaluates the suitability of the water concerning water treatment aspects for domestic use. This means that the Chilean norm does not have as high demands as the other two norms. The three norms classify the water quality depending on different parameters. These are shown in

[38] Science Dictionary, <http://www.sciencedictionary.org/enviromental-science-term-details/BOD5>, (2004-02-04)
[39] Water on the Web, <http://wow.nrri.umn.edu/wow/under/parameters/conductivity.html>, (2004-02-04)
[40] Water on the Web, <http://www.waterontheweb.org/under/streamecology/solids.html>, (2004-02-04)
[41] State Government of the Common Wealth of Kentucky, <http://www.state.ky.us/nrepc/water/wcpdo.htm>, (2004-02-04)

table 6.6.1b. Below the table follow an explanation of the norms and their different classes.

**Table 6.6.1b**: The parameters considered by three water quality norms: Chilean, Brazilian and European.

| Parameters | Chilean norm | Brazilian norm | European Union norm |
|---|---|---|---|
| $BOD_5$ | x | x | |
| Solid suspended matter | x | | |
| Nitrogen, total | x | | |
| Phosphate | | x | |
| Oil and grease | x | x | |
| Chlorine pesticides | x | x | x |
| Organic phosphorous pesticides | x | x | x |
| Copper | x | x | x |
| Iron | x | x | x |
| Fecal Coliformes | x | x | x |
| pH | x | x | |
| Temperature | x | | |
| Electrical conductivity | x | x | |
| Dissolved solids | x | x | |
| Dissolved oxygen | x | x | |

The quality ranges for the different systems are:

**Chilean norm**
The Chilean norm treats the suitability of the water from following points of views: Preservation of the environment, protection of aquatic communities, irrigation, development of the agriculture, water supply for animals and industrial use.

Following classes are applied in the Chilean norm:

- The exception class: Extraordinary clean water, definitely suitable for all the usages that are considered in the Chilean norm.
- Class 1 (very good quality): Water with very good quality, suitable in aquatic communities, for irrigation, development of agriculture and as drinking water for animals
- Class 2 (good quality): Water with good quality is suitable for development of agriculture, as drinking water for animals and for restricted irrigation.
- Class 3 (regular quality): Water with regular quality is suitable as drinking water for animals and restricted irrigation.
- Class 4 (bad quality): Water with bad quality is only appropriate for industrial use.

**Brazilian norm**
The Brazilian norm treats the suitability of the water from following points of views: domestic water supply, protection of aquatic communities, recreation (for example swimming and diving) and drinking water for animals.

Following classes are applied in the Brazilian norm:

- The exception class: Water that is suitable for domestic use after a simple disinfection.
- Class 1 (very good quality): Water that is suitable for domestic use after a conventional treatment. The water is also appropriate in aquatic communities and as recreation. The water can be used for irrigation of crops for human consumption.
- Class 2 (good quality): Water that is suitable for domestic use after a conventional treatment. The water is also appropriate in aquatic communities and as recreation. The water can be used for irrigation of vegetables and fruit-trees.
- Class 3 (regular quality): Water that is suitable for domestic use after a conventional treatment. The water can also be used for forest irrigation and as drinking water for animals
- Class 4 (bad quality): Water only suitable for less demanding usages.

**The European Union norm**
The European Union norm establishes the requirements of the treatment that is needed for drinking water and water for domestic use. There are three types of treatments:

- Category A1: Simple physical and chemical treatment and disinfection, for example rapid filter and disinfection.
- Category A2: Normal physical treatment, chemical treatment and disinfection, for example addition of chlorine, coagulation, flocculation, decantation and filtration.
- Category A3: Intensive physical and chemical treatment, extended treatment and disinfection. See the examples in category A2 but with more intensive and extended treatment.

A classification for the Pesé stream due to the three different norm systems and the two seasons, once for the dry season and once for the rain season is shown in tables 6.6.1c and 6.6.1d. The parameters that have the most negative influence on the water quality are shown as the cause.

**Table 6.6.1c**: Classification due to the three norms in the dry season, April 2002, for the measured place in Las Cabras, Pesé stream.

| Dry season | Classification according to the Chilean norm | Classification according to the Brazilian norm | Classification according to the European Union norm |
|---|---|---|---|
| Quality Class | Class 3 (regular quality) | Class 4 (bad quality) | Category A2 |
| Cause | Fecal Coliformes | Phosphate | Fecal Coliformes |

**Table 6.6.1d**: Classification due to the three norms in the rain season, October 2002, for the measured place in Las Cabras, Pesé stream.

| Rain season | Classification according to the Chilean norm | Classification according to the Brazilian norm | Classification according to the European Union norm |
|---|---|---|---|
| Quality Class | Class 4 (bad quality) | Class 4 (bad quality) | Not suitable |
| Cause | Fecal Coliformes, dissolved oxygen, nitrogen total and solid suspended matter | $BOD_5$ and phosphate | |

The tables show that the water has a bad quality during the whole year. According to the Chilean and Brazilian norm it is only appropriate for industrial use or less demanding usages during the rain season. During the dry season it is appropriate for drinking water for animals and restricted irrigation as well. It can also be used for drinking water for humans if it is treated the right way according to the European Union norm.

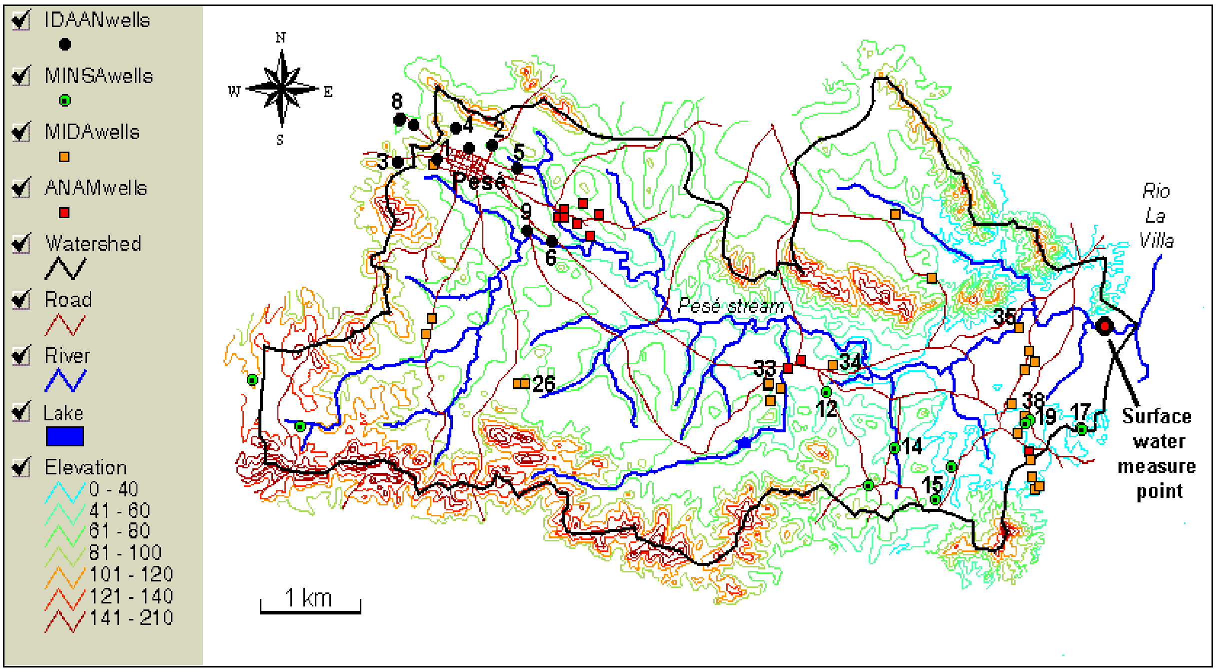


**Fig 6.6.1**: Map of the chemistry measure points in the study area.

## 6.6.2 Groundwater in the wells

### 6.6.2.1 IDAAN

In Pesé IDAAN takes water samples to do physical and chemical analyses. The analyses are done on water from the pipe once a month and on water from the wells once a year. Furthermore, bacteriological analyses are done once a week on water from the pipe and once a month on water from the wells.

To evaluate the water quality in the wells in the Pesé community, four sets of physical and chemical analyses were reviewed. The sets were from the four years 1999-2002. The values were compared with the threshold values for drinking water in Sweden.[42] These threshold values are for drinking water that is drinkable without any remarks. See Appendix G for all the values. The values written in bold font in the appendix are the ones that exceed the threshold value.

The different parameters that were analysed and the motivation[43] for the threshold values for drinking water are:
**pH:** Normally the pH-value is between 5,5 and 8,5 in drinking water. If the values are lower than 7,5 there is a risk for corrosion of the metals in the pipe.
**Conductivity:** The electrical conductivity increase when the chloride increases. It is often less than 100 mS/m. If the values are high this is often in relation with when the pH, alkalinity and hardness are low.
**Alkalinity:** Alkalinity indicates the buffered capacity of the water. If the alkalinity is high the water has a high ability to stand up to acidification. It should be higher than 60 mg/l to avoid corrosion of the pipes.
**Hardness, Calcium (Ca) and Magnesium (Mg):** Hardness is the summation of calcium and magnesium in the water. To calculate the total hardness on the basis of calcium and magnesium following formula is used[44]:
Total hardness [mg Ca/l] = mg Ca/l + 1.65 * mg Mg/l
Usually the formula is expressed in German Degrees of Hardness °dH:
Total hardness [°dH] = Total hardness [mg Ca/l] / 7.143
If the value of the total hardness exceeds 15 °dH the risk for precipitation on textiles and in the pipes is high. Another reason to keep the hardness low is that one need to use more soap and detergent the higher the value is. Calcium and magnesium originate from the bedrock and if the hardness value is high this indicates that there is a high velocity of the weathering process in the area.
**Chlorine (Cl):** If the content of chlorine is higher than 100 mg/l it can speed up the corrosion. Chlorine can be added to the water to kill bacteria.
**Nitrate ($NO_3^-$):** If the nitrate value is higher than 5 mg/l it has some remarks. One should not give the water to a child under one year if the nitrate exceeds 10 mg/l and if it

[42] Publice notice, Drinking water in Sweden, *Dricksvatten*, SLV FS 2001:30, <http://www.stockholmvatten.se/dricksvatten/vattenkvalitet/lovo.asp>, (2004-02-09)
[43] Vattenspecialisten EVK AB, *Analysresultat – Enskild Kemisk Undersökning*, <http://www.vattenspecialistenevk.se/kemisk.htm>, (2004-02-09)
[44] Naturvårdsverket, <http://www.naturvardsverket.se/dokument/mo/hbmo/del3/sotvatten/brunn.pdf>, (2004-02-10)

is over 30 mg/l it should not be used for drinking or cooking. Normally if the water has a high content of nitrate it comes from fertilized nearby land, leaking sewage or other pollution sources.
**Nitrite ($NO_2^-$):** If the nitrite value is higher than 0.005 mg/l it has some remarks. One should not give the water to a child under one year if the nitrite exceeds 0.050 mg/l and if it is over 0.30 mg/l it should not be used for drinking or cooking. Normally if the water has a high content of nitrite it comes from lack of oxygen in deep wells, but it can also come from fertilized nearby land, leaking sewage or other pollution sources. The reason why the threshold value is much lower for nitrite than for nitrate is that the human body does not have an enzyme which breaks down the nitrite. Nitrite deteriorates the oxygen reception in the blood.
**Sulphate ($SO_4^{2-}$):** If the content of sulphate is higher than 100 mg/l it can speed up the corrosion.
**Copper (Cu):** The content of copper should not exceed 0.05 mg/l. If it exceeds 0.20 mg/l it can be injurious for the health. It can also contribute to green precipitation on clothes and on sanitary pottery.
**Iron (Fe):** If the content of iron should exceed 0.1 mg/l it is not unhealthy but contributes to discoloration and deposits in the pipes.
**Fluoride (F):** If the content of fluoride is between 0.80-1.30 mg/l it has a preventive caries care.
**Turbidity:** Turbidity measures how muddy the water is. If the value is high this is probably because the water has a high content of iron or clay and it can be caused by the fact that surface water leaks into the well.

The values that exceed the threshold values are hardness, i.e. calcium and magnesium, nitrate, copper and turbidity, while pH had a value that is too low. But all of these, except nitrite, will not affect the human health in a bad way. Most of the thresholds values are for physical and mechanical reasons, such as to avoid corrosion of the pipes or to avoid deposits in the pipes. But the pipes in the area are made by plastic and have therefore no tendency to corrode. Another reason for the high threshold values is to avoid deposits on sanitary pottery and discoloration of cloths.

A more important test concerning the human health is the bacteriological test. Two tests with samples taken every month year 2000 and the most of the months of 2003 in the wells can be seen in Appendix H (the tests from 2001 and 2002 are not accessible). In the wells that have had problems with bacteria chlorine has been used. The concentration of chlorine is changed after the results of the bacteriological tests, but there is no information of how much chlorine that is used. For some reason there is no addition of chlorine in well 8 (well B9) even though the bacteriological amount is usually high in this well. Sometimes several wells have large amounts of bacteria and sometimes the values are high in the pipe system and this might be unhealthy for the users. But usually there are no or very little bacteria in the wells. It is hard to draw a conclusion if there are more bacteria in the wells during the dry period or during the rain period only by reviewing these two years of tests why no conclusions have been drawn.

#### 6.2.2.2 MINSA

The health authority, MINSA, analyses the water from wells that are used for domestic use in small communities. The only test that has been studied in this project is a bacteriological test that was analysed in September 2003. Water from the five wells in Cascajalillo (12), Arenita (14), Bulungo De La Arenita (15), Barriada Las Cabras (17) and Las Cabras (19) were included in the study. The only working wells in the project area that were not included in the study were those in Sabana Grande because of lack of information from these wells. The water samples were taken before the addition of chlorine and therefore they did not contain any chlorine. All the samples from the five wells show signs of bacteria why it is necessary to use chlorine in all these wells.

#### 6.2.2.3 MIDA

The agricultural development authority, MIDA, has made chemical and physical analyses of the water from new drilld wells. The analyses were made by TAHAL. The water from these wells will only be used for irrigation why the water quality does not have to be as good as for drinking water, but to make a comparison with the water quality in Pesé the values are matched up to the threshold values for drinking water in Sweden. In table 6.6.2 the values from the five wells 26, 33, 34, 36 and 38 can be seen together with the threshold values.

**Table 6.6.2**: Values from chemical and physical analyses of five MIDA-wells.

| | Well | month | pH | Conduc. | Alk. | Ca | Mg | Hardness | | Cl | $NO_3^-$ | $SO_4^{2-}$ | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no. | Owner | | | mS/m | mg/l | mg/l | mg/l | mg/l | °dH | mg/l | mg/l | mg/l | mg/l |
| 26 | Herberto Varela | Dec. | 6.5 | 40 | 201,3 | 52,8 | 16,1 | 79,3 | 11,1 | 28,4 | 4,3 | 13,0 | 0,2 |
| 33 | Reyes Solis | Jan. | 6,9 | 40 | 17,1 | 33 | 13,1 | 54,7 | 7,7 | 21,3 | 0,4 | 12,5 | |
| 34 | Irvin Osorio | Aug. | 6,8 | 73 | 290,4 | 40 | 5,0 | 48,2 | 6,8 | 43,2 | 3,7 | 29,3 | |
| 35 | Gabriel Mudarra | Aug. | 7 | 46 | 4,9 | 41 | 10,9 | 59,1 | 8,3 | 14,2 | 0,1 | 1,4 | |
| 38 | Abelina de Rodríguez | Sept. | 6,8 | 42 | 13,4 | 42 | 12,0 | 61,9 | 8,7 | 26,6 | 0,1 | 5,8 | |
| Threshold value | | | 7,5-9,0 | - | - | 100 | 30 | | 15 | 100 | 5 | 100 | 0,1 |

A big difference, compared to the water from the wells in Pesé, is the value of the hardness. Here the values are low, lower than the threshold value, but in Pesé the values are much higher. One reason could be that the bedrock differs some between the different areas. In Pesé there are mainly andesite, some calcite and tuff which include calcium and magnesium. In the countryside there are mainly sandstone and tuff which consist of less of these substances. But these differences should not show such a big difference in the amount of these substances in the water. Another reason could be that the analyses made by IDAAN are performed in the wrong way and that the amount of these substances is much lower than the values show.

## 6.7 Threats to the water resourses

### 6.7.1 Contamination of the surface and groundwater

Contamination of the water from different sources is a big threat for the water quality in the project area. The only treatment of the drinking water is addition of chlorine and since there is no other treatment the groundwater quality needs to be good. The surface water quality also needs to be good so that people can use the stream for recreation and animals can drink the water etc. without exposing themselves to dangerous substances in the water. Another reason is that the stream is a tributary to the river Rio la Villa which continues down to the Pacific Ocean and passes by the bigger towns Chitré and Los Santos on its way down. In Chitré the drinking water is not taken from wells, but from surface water of Rio la Villa which is purified in a treatment plant before being distributed to the users. Another reason for maintaining a good water quality of the surface water is that a bad quality can affect the ecological system in and around the stream, the river and the ocean.

**6.7.1.1 Sources of contaminations**

In the project area there are seven main sources of contaminations. These are:

- Domestic sewage, mainly from Pesé
- Pesticides, fertilizer and manure from the agriculture
- The pork breeding farm, Finca Fulo Crespo
- The alcohol distillery industry, Varela Hermanos S.A.
- Cattle breeding
- Domestic waste and garbage
- Interconnections of different layers and aquifers

**Types of contaminations from domestic sewage**

The domestic sewage is mainly from Pesé where water closets are used. This water is not treated in any way and is probably discharged directly into the Pesé stream. In the outskirt of Pesé and on the countryside outside lavatories are used which usually not affect the ground and surface water in the vicinity. However, if the outside lavatories are situated in a wrong place the contaminations can be a threat to the groundwater that is used for domestic use. This happens if the contaminations are not broken down before they reach the well. It can also be a threat to the surface water in the stream. Figure 6.7.1a shows outside lavatories close to a well house in Pesé.

**Fig 6.7.1a**: Photo of a well-house painted in white and blue close to an outside lavatory in the outskirt of Pesé.

The most common types of contaminations from domestic sewage are:

- Nitrogen, as ammoniac or organic
- Phosphor
- Bacteria
- Oil and grease
- Solid suspended matters
- Solid sediment matters

Drinking water should not contain any, or very little of the parameters listed above, especially bacteria can be dangerous to the health in very small quantities. Nitrogen and phosphorous are also important nutritive substances and can in a too big quantity contribute to eutrophication.

There is an organisation created for the purpose to stop the discharge of domestic sewage to the river Rio La Villa. If the organisation raises enough money they will build a treatment plant in Los Santos, to start with. This will not affect Pesé watershed directly, since Los Santos is much further downstream river Rio La Villa , but the knowledge that is spread will probably effect future work. A conspicuous poster by the main road in Los Santos with the text: 'No more sewage water to Rio La Villa, help us!' is shown as figure 6.7.1b.


**Fig. 6.7.1b**: Photo of a poster with the text:
'No more sewage water to Rio La Villa, help us!'

**Types of contaminations from the agriculture**

Agricultural pesticides, fertilizers and manure contribute with contaminations to the ground and surface water. If too much fertilizer or manure is used, the abundance can be washed off with rain to nearby ditches and streams or be transported to the groundwater.

Pesticides can be a big threat to the water in the area. According to swedish environmental agencies and organisations[45], there has not been made enough researches about the environmental affects from the use of pesticides in the agriculture. Not all the environmental affects are therefore known today. What is known is that the pesticides are not very selective and they kill more plants and animals than the specific noxious animal it was supposed to kill. They can also leak to streams and the groundwater without being broken down if the conditions are bad. The poisonousness and breaking down velocity of the pesticides, like all dangerous substances, are important for determination of the danger for humans.

According to professor Leonidas Rivera[46] at the Technical University of Panama the main contamination source in this area is pesticides used for sugarcanes and rice crops. He also says that pesticides that are forbidden in the United States are used in Panama even though there are regulations in the Panamanian law to provide this. The reason for that they are used against the law is that there is not enough money to control the use of the pesticides in the country. No written information has been found to confirm this, but nevertheless any that denies it.

The other sources of contamination from the agriculture are, as written above, fertilizers and manure. The most common types of contaminations from these are:

- Solid suspended matter
- Nitrogen

[45] Naturvårdsverket, <http://www.naturvardsverket.se/>, (2004-02-23) and Naturskyddsföreningen, <http://www.snf.se/> ,( 2004-02-23)
[46] Ing. Leonidas Rivera A., Facultad de Ing. Civil, UTP, 2003-09-23

**Types of contaminations from the pork breading farm**
The pork breeding farm, Finca Fulo Crespo lies in the middle of the study area, close to the Moreno stream that has an outflow in the Pesé stream one kilometre further down. The contaminations from the pigs are washed off with water from the two wells belonging to the industry and the dirty water is transported to an oxidation tank. Then the water is pumped from the tank to a land close to the Moreno stream and used for irrigation. Usually the contamination of the streams is little since the water from the farm is spread out and used as manure. But there is a risk that the oxidation tank gets overloaded during the rain period. This can cause that contaminated water goes directly to the Moreno stream. Another risk during the rain period is that the irrigation water can be washed off the land and swept of directly to the steam.

The most common types of contaminations from the pork breading factory are:

- BOD5
- Solid suspended matter
- Nitrogen
- Phosphor
- Coliformes

Every year approx. 3200 pigs are produced in this farm and the discharge is approx. 5100 $m^3$/year. The industry produces approx. 583 000 kg solid suspended matter per year and 26800 kg nitrogen[47].

**Types of contaminations from the alcohol distillery industry**
The alcohol distillery industry, Varela Hermanos, is situated one kilometre southeast of Pesé. The Pesé stream runs approx. 100 m from the industry. All the waste water from the industry, 57 300 $m^3$ per year[48], is transported to tanks. The water is then used for irrigation during the dry period. According to the water quality project made by ANAM there is no water that goes directly to the stream, but to keep such a big amount as almost 57 000 $m^3$ during a year in two-three tanks seems impossible to the authors, if the tanks are not huge. This means that some wastewater is probably going to the Pesé stream, especially during the rain period.

The most common types of contaminations from the liquor industry are:

- BOD5
- Solid suspended matter
- Total dissolved solids

Figure 6.7.1c shows one of the wells used for the industry and the sugar cane mill in the background.

[47] Autoridad Nacional del Ambiente, ANAM, *Proyecto Piloto de Monitoreo de la Calidad del Agua de la Cuenca del Río La Villa, Provincias de Herrera y Los Santos y su aplicación en las Principales Cuencas Hidrográficas de Panamá,* April 2003
[48] Idib.

**Fig. 6.7.1c**: Photo of a well in front of the Varela Hermanos sugar cane mill.

**Types of contaminations from cattle breading**
In the study area a lot of land is used for cattle breeding. The contaminations from the cattle, deriving from excrement and stale, can be transported to ground and surface water. But the risk is little since it is spread out over a big area and is in small concentrations working as manure.

The most common types of contaminations from cattle breading are:

- Solid suspended matter
- Nitrogen
- Phosphor
- Coliformes

If the water has a high concentration of these types of contaminations they contribute to eutrophication. High concentration is also unhealthy for people, see chapter 6.6, Water quality.

**Types of contaminations from domestic waste and garbage**
In some places garbage is not taken care of properly. It has been left by the side of the road or by the stream. It can leak unhealthy substances to the surface and groundwater. Figure 6.7.1d is taken close to well 5 (B6) in Pesé with a ditch leading to Pesé stream close by.

**Fig. 6.7.1d**: Photo of garbage by the stream in the outskirt of Pesé.

**Interconnections of different layers and aquifers**
When wells are being drilled the drilled holes link the surface water to the groundwater and the groundwater in the different layers, fractures and aquifers together. Impermeable layers in the ground stop the contaminations from spreading between the layers but interconnection between the different water bodies can cause spreading of contaminations from one water body to another. In this area, where many wells are being drilled to find enough water, the interconnections are many and the threat to the groundwater is big.[49]

## 6.7.2 Exhaustion of the aquifers

If too much water is withdrawn from the wells this can cause exhausting of the aquifers. In pumping tests, see chapter 5.4 Analyses of pumping tests, a maximal discharge without exhausting the aquifer is calculated, called $Q_{balance}$. If this discharge is miscalculated or is exceeded the aquifer can dry out.

[49] Lic. Gonzalo A. Menéndez G., Assistant Manager, ANAM, 2003-09-25

### 6.7.3 Extreme weather and climate situations

Another big threat for the area is extreme weather and climate situations. Extreme climate and weather situations occur more often all over the world. It is a bigger threat today than it was some decades ago. If the climate and weather change and it rains less, this will affect the water supply in the area in a bad way. The project area and the area around it is already the driest area in the country and if it rains less this may affect the amount of the water in the aquifers.

**El Niño and La Niña**
The biggest climate threat is El Niño, a phenomenon that occurs those years when the currencies in the Pacific Ocean changes compared to their normal routes. The years it occurs the climate gets warmer and it does not rain as much as a normal year. The last years that El niño occurred were 1986-1987, 1991-1992, 1993, 1994 and 1997-1998[50]. These years pretty much agree with the dry years chosen for the water supply calculations in chapter 6.5. The opposite to El Niño is La Niña and then the climate gets colder and it rains more, which is good for the water supply. Year 1997 was El Niño unusually strong but La Niña that followed was extraordinarily cold and wet. That means that maybe el niño is not a big threat since la niña follows with more rain that compromise the water lost. According to a study made by Tahal[51] for MIDA, the changes of the groundwater level because of climate changes are clear and big, but the recovery of the aquifers are quick when it starts to rain more again.

[50]Pacific Marine Environmental Laboratory, <http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html> , (2004-02-24)
[51] Tahal Consulting Engineers LTD, *Proyecto de Riego del Arco Seco, Informe Final – Hidrogeología*, May 2003

# 7 Results

The results of the study are as follow:

**Establishment of a database of the wells in the area to collate information from different sources in one place.**
A database with information from nearly all the wells in the Pesé stream area has been established. The database includes information about whether the well is in use or not age, location, depth, elevation, drilling information pump-test parameters, working discharge and water use information and if there exists a geological profile. The database is not complete since most of the wells have some lack of information. Yet the database gives an overview of the wells and simplifies the study of the groundwater since the necessary information is gathered in one place. The database will be accessible for the public and for all the authorities that are in charge of the water supply. The idea is that this type of database will function as a model for future compilation of well information.

**Localisation and classification of the aquifers according to discharges from wells**.
To localise the aquifers is complicated. It is difficult to define exactly where there are good chances to find water. For example is one well with a high discharge situated close, approx. 20 meters, to wells with no discharge at all. This shows that an aquifer can be situated very close to an aquiclude. The interpolations made in this study are rough estimations of where there are aquifers and they do not take into consideration variations of the geology in the interpolated areas.

**Presentation of the geology, how the aquifers are situated and the groundwater flow pattern.**
It is essential to study the geology in order to know where there are good aquifers. The main rock types in the study area are sandstone, tuff, andesite and basalt, all covered with a layer of clay. Usually there is a weathered rock layer under the clay. The geology varies and due to lack of information it is hard to find geological patterns. If a core is taken it would be possible to study the geology and find out if there are chances to find enough water. By studying the geological profiles the conclusion is drawn that most of the aquifers are placed in the weathered rock layer above the fresh rock. The best aquifers are found in weathered rock and in limestone. Water is rarely found in compacted andesite and compacted basalt.

The Pesé stream is fed with water from groundwater reservoirs and the stream is considered as a discharge area while the areas higher up in the watershed are considered as recharge areas.

**View of the water use today and the prognosis for the nearby future.**
In total, the water used from groundwater is almost one million cubic meters per year in the project area. Over half of the water used in the area is used for domestic care. Over twenty percent is used for irrigation and about the same amount is used by the industries.

The water consumption will probably increase some in the future. The reason is the growing of the population in the project area, but the growing rate is small and does not affect the outtake from the wells very much. In the future irrigation areas might increase and this will also increase the water consumption, but the chances for that are small. Today five farmers in the area use irrigation and even though more farmers would like to use groundwater for irrigation the chances to find enough water in other places than the ones used today are small. Drilling attempts have been made in several parts of the area without finding enough water.

**Estimation of how much water the aquifers can supply.**
Comparing the outflow with the water use, the water use today is very low. The outflow is approx. 10.6 million $m^3$ and the water use is approx. 1 million $m^3$. However, one has to consider that the conditions for the investigated Rio La Villa watershed may not be the same as for the applied Pesé stream area. For example the aquifers in the study area may not be as good as the ones in the higher elevated Rio La Villa watershed, and perhaps there are less people, comparing with the study area, who are using the groundwater in this big area. It is also known that the precipitation is lower in the lower parts of the watershed than in the higher parts. The calculated part is in the higher part and Pesé stream area is in the lower part.

Since the aquifers in the study area are located in weathered rocks, fractured zones and in pores in the fresh rock, the size and magazine volume of the aquifers can vary a lot. It is therefore important to do an accurate pumping test every time a well is drilled to determine the performance characteristics and the hydraulic parameters of this specific aquifer. In some areas, the aquifers may supply a lot of water and in others areas, there is no water at all. The water from the aquifers shall supply water for domestic use, for irrigation and for industrial production but it is also important to retain water in the stream as an ecological discharge. Therefore, not all water can be consumed.

**Evaluation of the surface and groundwater quality.**
The surface water has a bad water quality during the whole year. According to three studied norms, the water is only appropriate for industrial use or less demanding usages during the wet season. During the dry season, it is appropriate for drinking water for animals and restricted irrigation as well. It can also be used for drinking water for humans if it is treated the right way according to one of the norms during this period.

The groundwater in the area is taken directly from the wells. Compared to Swedish threshold values for drinking water the quality is bad, but that does not mean that the water is unsuitable for humans to drink. Most of the threshold values are for physical and mechanical reasons. The only negative aspects about the water quality are that the water might smell or taste a little and the contaminations can contribute to deposits in pipes and on sanitary pottery and cause discoloration of clothes. Nitrite and fecal coliformes (bacteria) are the only substances with too high values that should be attended to because of the health risk that these provide. The only treatment of the water used for domestic purpose is the addition of chlorine and this affects the bacteria. To transform nitrite oxygen is needed, and hopefully, enough oxygen is in contact with the water before it is used.

**Description of the main threats today.**
The main threats to the water recourses in the area today are contaminations from different contamination sources and extreme climate situations. The main contamination sources are sewage from the industries and the community in the area and contaminations from the agriculture.

It is difficult to say how big the contamination threats from domestic sewage, waste and garbage are. If the water closets and wastewater from sinks in Pesé are discharged directly into the Pesé stream this will be a big contamination source. The main contaminations are nutrients and bacteria, but there are also other contaminations for example oil and grasses that are flushed down that can affect people, plants and animals in the ecological cycle. Waste and garbage that is not taken care of the right way can also contribute to contaminations as unhealthy substances can spread in the water.

One big threat is pesticides used in agriculture. How big the threat is depends on what kind of pesticide that is used and in what amount. Indications has been made that very strong pesticides are used in the project area that are forbidden for use in the USA. These can harm many more animals and plants than the intended noxious spices. It can also be harmful for people who get in contact with the pollution. Other contamination sources from the agriculture are fertilizers and manure. These can contribute to eutrophication if being spread to water bodies in the area.

The industries, one alcohol distillery and one pork breeding farm, do not discharge the wastewater directly to the stream, instead they use the water for irrigation during the dry period. The contaminations can still reach the water resources with runoff, infiltration or when there is more wastewater than the wastewater system can handle or with water flood. Another risk lies in the tanks that hold the water until it is time for irrigation. If the tanks are not big enough wastewater is led directly to nearby streams for some time during the rain period. The contaminations in the wastewater can lead to eutrophication and is unhealthy for people if the concentration is high.

Another threat is the drilled wells. Drilling through different layers cause contact between different water bodies where contaminations can be spread.

It is important not to exceed the maximum discharge, $Q_{balance}$, for the well. This can cause that the aquifer dry out.

Extreme climate situations, especially drought, can cause shortage of water. The most common climate change in the region is El Niño. When this weather phenomenon occurs, the weather gets hotter and dryer than normally. But after El Niño comes La Niña with colder and wetter weather and the water bodies that has dried is filled up with water once more.

# 8 Conclusions

The following conclusions have been drawn in this study:

- A better documentation of the well drillings is needed in a joint database that is available for the public and for the authorities responsible for the water supply. The database that has been developed in this study can be used as a model for future compilation of well information.

- According to interpolations of the discharges from the wells the aquifers are situated north and east of Pesé, around Llano Barrero and down towards La Arenita.

- The geology in the study area mainly consists of sandstone, tuff, andesite and basalt. The aquifers are generally placed in weathered rock layers and the best aquifers are situated in weathered rock and limestone.

- The water resources in the study area are bigger than the water use and the use will probably not increase in the nearby future. Uncertainty of the size of the water resources is high and the size of the water resources can be much smaller than the calculations in this study shows.

- The surface and groundwater quality is bad in the study area during the whole year, especially in the rainy period. After addition of chlorine the groundwater is in most cases suitable for drinking.

- Main threats to the fresh water are pesticides and fertilizers from agriculture, domestic sewage and sewage from industries. Other threats are exhaustion of the aquifers and climate changes.

# 9 Recommendations

**Documentation of all drillings**
It is important to document all drillings with information of the geology and the water discharge. Today there is no documentation of non successful drillings and there is not enough documentation concerning the drillings of the wells that are in use. It is necessary to document all drillings in order to locate the aquifers and aquicludes.

**Gather the data in one place**
It is also important to keep all the information in one place. Today the documentation that exists of the wells is kept at the different authorities that are in charge of the wells. There is no joint record with information about all the wells. A joint record would facilitate the location of the aquifers and aquicludes. All the data about the wells need to be gathered in one place, in order to draw conclusions about the groundwater and the aquifers.

The suggestion is that the type of database that has been established in this thesis should function as a model for future compilation of well information. The suggestion of database can be arranged differently but it should consist of the same parameters for all the institutes, IDAAN, MINSA, MIDA and ANAM, and all the private persons who drill wells. This formula should include at least location, geology, groundwater levels, discharge, well design, pumping test, pumping test results and a clarification in which geological layer that aquifers are found. If a core was taken, then this information should also be included in the template.

**The importance of spreading information**
Among the authorities that are in charge of the water supply in Panama there exists an unwillingness to share information. If the management of water resources is to be improved, there must be a more open mentality to share information.

**Core**
The geology information that exists is very approximate since no cores have been taken in the area. A recommendation is to take cores in the area and to organise and compile the information from these. With a core it is possible to see how the geological layers are situated, the characteristics of the geological matter, where there are fractured zones and how the fractures are raked. This would simplify the survey of aquifers in the whole area, but it is difficult to say if it is economically justifiable.

**New laws**
A scientific draft over the area is needed. ANAM would be interested in a first draft of an environmental plan concerning management for groundwater.
To make a "law" that proclaims: If somebody drills a well they have to apply for permission to drill, report what the geology is in the drill hole and if water was found, a rough description of the water quality.

# 10 Future studies

Following suggestions for future studies are:

- Make a continuation of this study in the dry period, since the project could only be performed in the rain period. This would give a more complete view of the groundwater situation.

- Measure the base flow in the Pesé stream in order to calculate a more accurate value of the water supply. Today the calculation of the water supply is based on the base flow of Rio La Villa upstream Pesé watershed. This can give an incorrect estimation since there are differences in the hydrogeological conditions in the areas.

- Extend the joint well database geographically and implement investigations to answer the following questions:
  - How can the database be introduced to the authorities?
  - How is the best way for the authorities to assemble the information into one place?
  - How can a continuous registration of well drillings be executed in a practical and easy system?

- Investigate how a better cooperation and communication between the authorities can be established. This is a difficult task because the mentality today in the whole society is an unwillingness to share information between one another. One way to change the mentality can be to start with teaching the importance of sharing and helping one another in schools.

- Investigate the advantages and disadvantages of taking a core. Is it economically defensible to take a core every time a well is drilled? It might be more expensive to take a core than to drill directly, but in a longer time perspective it will probably be profitable since the knowledge of the hydrogeology in the area will increase.

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# Appendices

## Appendix A: Pictures from Pesé stream watershed

1. View from the land of Heiberto Varela

2. Pesé stream close to the outlet to Rio la Villa

3. View from the land of Irwin Osorio

4. View from the land of Reyes Solis

5. View from the land of Heiberto Varela with plantation of corn.

6. View from the land of Carmen Esilda Ureña with plantation of corn.

7. A pump house for a well in Sabana Grande

## Appendix B1: Database with wells from IDAAN and MINSA.

| Authority | | Community | Well no | in use | Age | coordinates | |
|---|---|---|---|---|---|---|---|
| | | | | (x=yes) | | x | y |
| IDAAN | 1 | Pesé | B1 | x | The oldest | 542014 | 874045 |
| | 2 | Pesé | B3 | x | sep-69 | 542769 | 874237 |
| | 3 | Pesé | B4 | no | april-75 | 541478 | 874019 |
| | 4 | Pesé | B5 | no | march-81 | 542277 | 874459 |
| | 5 | Pesé | B6 | x | maj-84 | 543101 | 873944 |
| | 6 | Pesé | B7 | x | sep-90 | 543581 | 873002 |
| | 7 | Pesé | B8 | no | june-92 | 541510 | 874549 |
| | 8 | Pesé | B9 | x | july-95 | 541529 | 874564 |
| | 9 | Pesé | B10 | x | july-95 | 543256 | 873149 |
| | 10 | Pesé | reserve 2 | no | july-00 | 542450 | 874200 |
| | 11 | Pesé | reserve 1 | no | july-00 | 541700 | 874500 |
| MINSA | 12 | Cascajalillo | 1 | x | 12-sep-96 | 547329 | 871080 |
| | 13 | Arenita | 1 | no | | 547907 | 869891 |
| | 14 | Arenita | 2 | x | | 548263 | 870365 |
| | 15 | Bulungo de La Arenita | 1 | x | 20-nov-96 | 548827 | 869703 |
| | 16 | Bulungo de La Arenita | 2 | x(summer) | *95* | 549046 | 870123 |
| | 17 | Barriada Las Cabras | 1a | x | | 550810 | 870614 |
| | 18 | Barriada Las Cabras | 1b | no | | 550825 | 870595 |
| | 19 | Las Cabras | 1 | x | *83* | 550107 | 870729 |
| | 20 | Las Cabras | 2 | x(summer) | *98* | 550053 | 870678 |
| | 21 | Sabana Grande | 1 | x | *78* | 539502 | 871238 |
| | 22 | Sabana Grande | 2 | x | *83* | 540153 | 870649 |

*Italics = info said by Genaro Marciaga, responsible for the MINSA wells in the area, or by the operator.*

| | | |
|---|---|---|
| 1 feet = | 0,3048 | m |
| 1 gallon = | 3,7854 | dm3 |

| | Elevation | Depth | | During drilling | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | water table/s | | | | discharge (approx.) | |
| | (m.a.s.l.) | (feet) | (m) | 1 (feet) | 2 (feet) | 1 (m) | 2 (m) | (gpm) | (m3/h) |
| 1 | | | | | | | | | |
| 2 | | 180 | 55 | | | | | | |
| 3 | | 180 | 55 | | | | | | |
| 4 | | 206 | 63 | | | | | | |
| 5 | | 200 | 61 | | | | | | |
| 6 | | 163 | 50 | | | | | | |
| 7 | | 135 | 41 | | | | | | |
| 8 | | 165 | 50 | | | | | | |
| 9 | 80 | 157 | 48 | | | | | | |
| 10 | 70 | 180 | 55 | | | | | | |
| 11 | 70 | 205 | 62 | | | | | | |
| 12 | | 140 | 43 | | | | | | |
| 13 | | *85* | 26 | | | | | | |
| 14 | | *140* | 43 | | | | | | |
| 15 | | 135 | 41 | | | | | | |
| 16 | | *150* | 46 | | | | | | |
| 17 | | 135 | 41 | | | | | | |
| 18 | | *150* | 46 | | | | | | |
| 19 | | *200* | 61 | | | | | | |
| 20 | | *150* | 46 | | | | | | |
| 21 | | *140* | 43 | | | | | | |
| 22 | | *140* | 43 | | | | | | |

Database with wells from MIDA and ANAM.

| | Pumping test | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | x=yes | date | duration | Static level | | Dyn. level | | Drawdown | Qbalance | | Qmean | |
| | | | (h) | (feet) | (m) | (feet) | (m) | (m) | (gpm) | (m3/h) | (gpm) | (m3/h) |
| 1 | | | | | | | | | | | | |
| 2 | | | | 20 | 6,1 | 30 | 9,1 | 10 | | | 100 | 22,7 |
| 3 | | | | 20 | 6,1 | | | | | | | |
| 4 | x | march-81 | 48 | 40 | 12,2 | 51 | 15,5 | 11 | | | 83 | 18,9 |
| 5 | | | 46 | 6 | 1,8 | 17 | 5,2 | 11 | | | 65,4 | 14,9 |
| 6 | | | | 12 | 3,7 | | | | | | *70* | 16 |
| 7 | x | june-92 | 50 | 22 | 6,7 | 33 | 10,1 | 11 | | | 34 | 7,7 |
| 8 | | | | 15 | 4,6 | | | | | | *27* | 6 |
| 9 | | | | | | | | | | | *50* | 11 |
| 10 | x | aug-00 | 24 | 19,7 | 6,0 | 32 | 9,8 | 12,3 | 66 | 14,99 | | |
| 11 | x | aug-00 | 48 | 17,1 | 5,2 | 26,3 | 8,0 | 9,2 | 66 | 14,99 | | |
| 12 | x | 12-sep-96 | 4 | 8 | 2,4 | 16 | 4,9 | 8 | | | 60 | 13,6 |
| 13 | | | | | | | | | | | | |
| 14 | | | | | | | | | | | *60* | 13,6 |
| 15 | x | 20-nov-96 | 2,5 | 4 | 1,2 | 12 | 3,7 | 8 | | | 60 | 13,6 |
| 16 | | | | *15* | 4,6 | *25* | 7,6 | 10 | | | *40* | 9,1 |
| 17 | x | 20-nov-96 | 4 | 6 | 1,8 | 14 | 4,3 | 8 | | | 30/40* | 6,8/9,1 |
| 18 | | | | | | | | | | | | |
| 19 | | | | *4* | 1,2 | *10* | 3,0 | 6 | | | *60* | 13,6 |
| 20 | | | | *10* | 3,0 | *30* | 9,1 | 20 | | | | |
| 21 | | | | *5* | 1,5 | *8* | 2,4 | 3 | | | *60* | 13,6 |
| 22 | | | | *2* | 0,6 | *25* | 7,6 | 23 | | | *60* | 13,6 |

| | Qneeded | | Work pattern | Water use | | |
|---|---|---|---|---|---|---|
| | | | | summer, 182 days | winter, 182 days | Total |
| | (gpm) | (m3/h) | | (m3/season) | (m3/season) | (m3/year) |
| 1 | 32 | 7,3 | Work 30 hours, rest 18 hours. | 19893 | 19893 | 39785 |
| 2 | 56 | 12,7 | Work 30 hours, rest 18 hours | 34858 | 34858 | 69715 |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | 83 | 18,9 | 6-18 every day | 41245 | 41245 | 82490 |
| 6 | 40 | 9,1 | Work 30 hours, rest 18 hours | 24820 | 24820 | 49640 |
| 7 | | | | | | |
| 8 | 32 | 7,3 | Work 30 hours, rest 18 hours | 19893 | 19893 | 39785 |
| 9 | 40 | 9,1 | 6-18 every day | 19893 | 19893 | 39785 |
| 10 | | | | | | |
| 11 | | | | | | |
| | | | Sum: | 160600 | 160600 | 321200 |
| 12 | 35 | 7,9 | Automatic | 10664 | 10664 | 21328 |
| 13 | | | | 13392 | 13392 | 26784 |
| 14 | *40* | 9,1 | 3-7 am and 16-20 pm | | | |
| 15 | *40* | 9,1 | 14-16.30 pm | 7688 | 7688 | 15376 |
| 16 | *30* | 6,8 | Only summer | | | |
| 17 | *40* | 9,1 | Automatic | 9920 | 9920 | 19840 |
| 18 | | | | | | |
| 19 | *60* | 13,6 | 8 h every day | 25544 | 25544 | 51088 |
| 20 | *30* | 6,8 | Only summer | | | |
| 21 | *60* | 13,6 | 4-9 am | 21080 | 21080 | 42160 |
| 22 | *60* | 13,6 | 4-12 am | 20336 | 20336 | 40672 |
| | | | Sum: | 108624 | 108624 | 217248 |

Database with wells from MIDA and ANAM.

| | Geological profile (x=exist) | Notes |
|---|---|---|
| 1 | | |
| 2 | no | |
| 3 | no | Is not working at the moment because the machinery has stopped, but will start again. |
| 4 | x | Is not working at the moment because the machinery has stopped, but will start again. |
| 5 | x | |
| 6 | x | |
| 7 | x | Collapsed. |
| 8 | x | |
| 9 | x | |
| 10 | x | |
| 11 | x | |
| 12 | no | Automatic. It exists another well, but there is no info. about that one. |
| 13 | no | Manual pump, not working. |
| 14 | no | |
| 15 | no | |
| 16 | no | |
| 17 | no | *New pumping test showed a new discharge. |
| 18 | no | |
| 19 | no | |
| 20 | no | |
| 21 | no | |
| 22 | no | |

# Appendix B2: Database with wells from MIDA and ANAM.

| Authority | | Owner/ Factory | Well no | in use (x=yes) | Age | coordinates x | coordinates y |
|---|---|---|---|---|---|---|---|
| MIDA | 23 | Carmen Esilda Ureña | 1 | no | 7 april 2003 | 541966 | 872039 |
| | 24 | Carmen Esilda Ureña | 2 | no | 8 april 2003 | 541888 | 871826 |
| | 25 | Heriberto Varela | 1 | no | 13-nov-02 | 543138 | 871199 |
| | 26 | Heriberto Varela | 2 | x(summer) | 13-nov-02 | 543227 | 871204 |
| | 27 | Mario Argona | 1 | x(summer) | approx oct 2002 | 541985 | 873993 |
| | 28 | Reyes Solis | 1 | no | approx oct 2001 | 546582 | 870972 |
| | 29 | Reyes Solis | 2 | no | approx oct 2001 | 546721 | 871137 |
| | 30 | Reyes Solis | 3 | no | approx oct 2001 | 546544 | 871181 |
| | 31 | Reyes Solis | 4 | no | approx oct 2001 | 546544 | 871189 |
| | 32 | Reyes Solis | 5 | no | approx oct 2001 | 546550 | 871188 |
| | 33 | Reyes Solis | 6 | x(summer) | 18 dec 2001 | 546557 | 871189 |
| | 34 | Irwin Osorio | old | no | | 547442 | 871425 |
| | " | Irwin Osorio | redrilled | x(summer) | | " | " |
| | 35 | Gabriel Mudarra | 1 | no | 31 july 2001 | 549972 | 871907 |
| | 36 | Gabriel Mudarra | 2 | x(summer) | 31 july 2001 | 549954 | 870569 |
| | 37 | Abelina de Rodríguez | Equipado | x(summer) | | 549868 | 870940 |
| | 38 | Abelina de Rodríguez | Tahal | x(summer) | 1 Aug 2001 | 550054 | 870771 |
| | 39 | Juan Cedeño | | no | approx july 2003 | 548786 | 872553 |
| | 40 | Ulbino Rodríguez | 1 | no | approx oct 2002 | 548279 | 873366 |
| | 41 | Miguel Coba | 1 | no | 08-feb-01 | 550198 | 869850 |
| | 42 | Miguel Coba | 2 | no | 08-feb-01 | 550132 | 870227 |
| | 43 | Miguel Coba | 3 | no | 09-feb-01 | 550159 | 869998 |
| | 44 | Miguel Coba | 4 | no | 10-feb-01 | 550254 | 869886 |
| | 45 | Ismael Guerra | 1 | no | 27-july-01 | 550045 | 871373 |
| | 46 | Ismael Guerra | 2 | no | 30-july-01 | 550197 | 871481 |
| | 47 | Ismael Guerra | 3 | no | 21-aug-01 | 550120 | 871611 |
| ANAM | 48 | Alcoholes del Istmo, S.A. | 1 | x | *1925* | 550122 | 870317 |
| | 49 | Varela Hermanos | 1 | x | 1975 | 544234 | 873365 |
| | 50 | Varela Hermanos | 2 | x | 1975 | 544022 | 873503 |
| | 51 | Varela Hermanos | 3 | x | 1975 | 543938 | 873244 |
| | 52 | Varela Hermanos | 4 | x | 1975 | 543680 | 873320 |
| | 53 | Varela Hermanos | 5 | x | 1975 | 543755 | 873422 |
| | 54 | Varela Hermanos | 6 | x | 1975 | 543755 | 873320 |
| | 55 | Varela Hermanos | 7 | x | 1975 | 544114 | 873074 |
| | 56 | Finca Fulo Crespo | 1 | x | 1980 | 546819 | 871392 |
| | 57 | Finca Fulo Crespo | 2 | x | 1980 | 546998 | 871495 |

| | | |
|---|---|---|
| 1 feet = | 0,3048 | m |
| 1 gallon = | 3,7854 | dm3 |

Database with wells from MIDA and ANAM.

| | Elevation | Depth | | During drilling | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | water table/s | | | | discharge (approx.) | |
| | (m.a.s.l.) | (feet) | (m) | 1 (feet) | 2 (feet) | 1 (m) | 2 (m) | (gpm) | (m3/h) |
| 23 | | 60 | 18 | | | | | | |
| 24 | | 140 | 43 | 42 | 55 | 13 | 17 | | |
| 25 | | 140 | 43 | 32 | | 10 | | 10 | 2 |
| 26 | | 145 | 44 | 25 | 70 | 8 | 21 | 60 | 14 |
| 27 | | 100 | 30 | 20 | | 6 | | 5 | 1 |
| 28 | approx. 58 | 140 | 43 | | | | | 0 | 0 |
| 29 | approx. 58 | 140 | 43 | | | | | 0 | 0 |
| 30 | approx. 58 | 140 | 43 | | | | | 0 | 0 |
| 31 | approx. 58 | 140 | 43 | | | | | 45 | 10 |
| 32 | approx. 58 | 120 | 37 | | | | | 100 | 23 |
| 33 | approx. 57 | 120 | 37 | 38 | | 12 | | 100 | 23 |
| 34 | 46 | 100 | 30 | | | | | | |
| " | " | 105 | 32 | | | | | | |
| 35 | | 120 | 37 | | | | | 60 | 14 |
| 36 | 38 | 120 | 37 | | | | | | |
| 37 | 45 | | | | | | | | |
| 38 | 44 | 120 | 37 | 40 | 60 | 12 | 18 | 60 | 14 |
| 39 | | 105 | 32 | 10 | | 3 | | 25 | 6 |
| 40 | | 100 | 30 | | | | | 18 | 4 |
| 41 | | 100 | 30 | | | | | | |
| 42 | | 240 | 73 | | | | | 17 | 4 |
| 43 | | 100 | 30 | | | | | 5 | 1 |
| 44 | | 160 | 49 | | | | | 20 | 5 |
| 45 | | 140 | 43 | | | | | 0 | 0 |
| 46 | | 140 | 43 | | | | | 0 | 0 |
| 47 | | 60 | 18 | | | | | 0 | 0 |
| 48 | | *135* | 41 | | | | | | |
| 49 | | 180 | 55 | | | | | | |
| 50 | | 180 | 55 | | | | | | |
| 51 | | 200 | 61 | | | | | | |
| 52 | | 200 | 61 | | | | | | |
| 53 | | 200 | 61 | | | | | | |
| 54 | | | | | | | | | |
| 55 | | | | | | | | | |
| 56 | | | | | | | | | |
| 57 | | | | | | | | | |

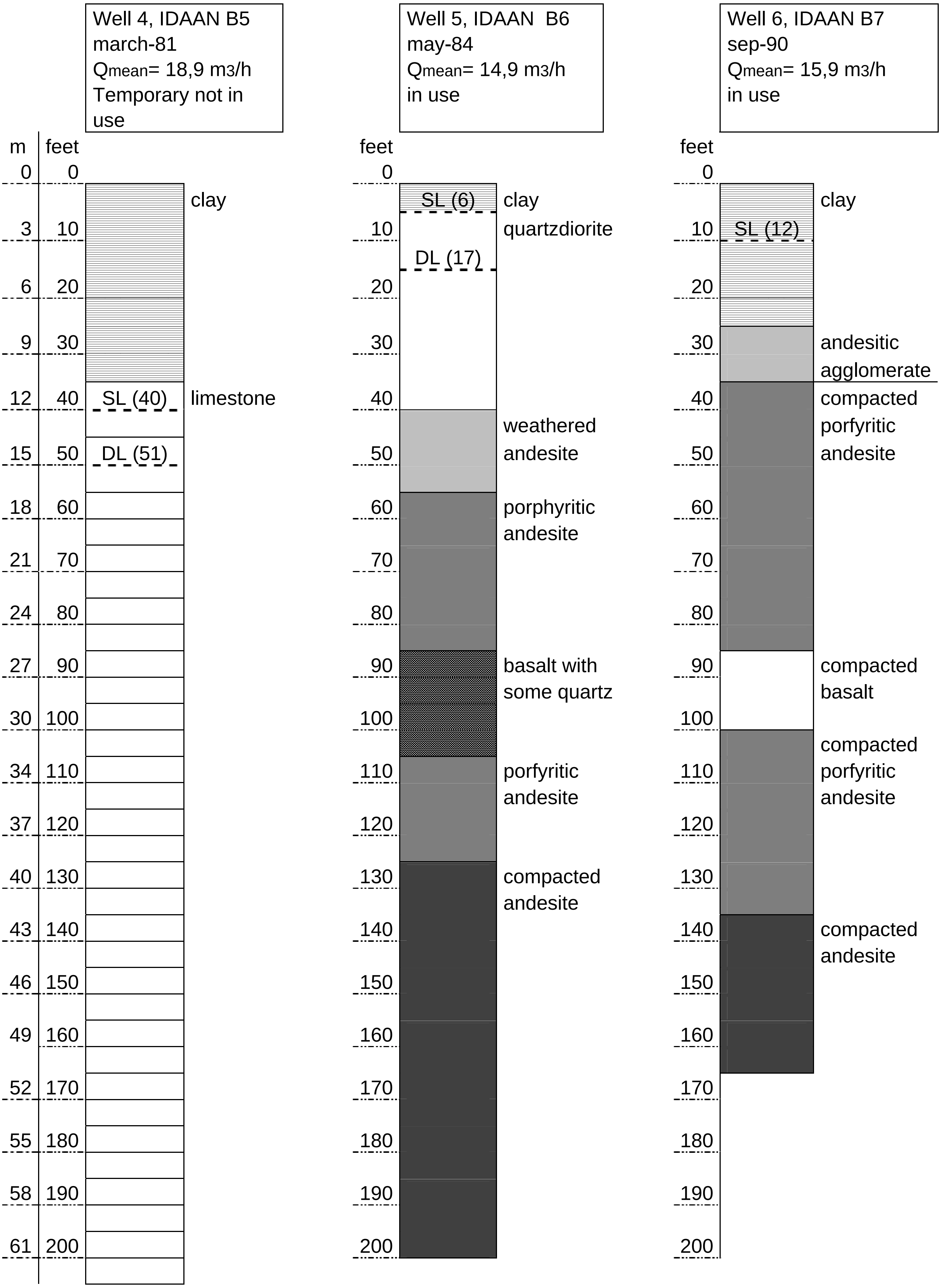
| | Pumptest | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | x=yes | date | time | Static level | | Dyn. level | | Drawdown | Qbalance | | Qmean | |
| | | | (h) | (feet) | (m) | (feet) | (m) | (m) | (gpm) | (m3/h) | (gpm) | (m3/h) |
| 23 | | | | | | | | | | | | |
| 24 | x | 14 april-03 | | 24,6 | 7,5 | 33,9 | 10,3 | 2,8 | 91 | 20,4 | | |
| 25 | | | | | | | | | | | | |
| 26 | x | 20-nov-02 | | 11,2 | 3,4 | 79,9 | 24,4 | 21,0 | 38 | 8,6 | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | |
| 32 | x | 15-okt-03 | | 12,8 | 3,9 | 36,3 | 11,1 | 7,2 | 43 | 9,8 | | |
| 33 | x | 20-dec-01 | | 4,6 | 1,4 | 15,9 | 4,8 | 3,4 | 130 | 29,5 | | |
| 34 | x | 26 aug 02 | | 13,8 | 4,2 | 17,2 | 5,3 | 1,1 | 120 | 27,2 | | |
| " | x | 15-july-03 | | 9,8 | 3 | 20,9 | 6,4 | 3,4 | 120 | 27,2 | | |
| 35 | | | | | | | | | | | | |
| 36 | x | 7 aug 01 | | 10,6 | 3,2 | 62,4 | 19,0 | 15,8 | 40 | 9,1 | | |
| 37 | | | | | | | | | | | | |
| 38 | x | 6 aug 01 | | 26,8 | 8,2 | 59,9 | 18,3 | 10,1 | 40 | 9,1 | | |
| 39 | | | | | | | | | | | | |
| 40 | | | | | | | | | | | | |
| 41 | | | | | | | | | | | | |
| 42 | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | |
| 44 | | | | | | | | | | | | |
| 45 | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | |
| 48 | | | | | | | | | | | | |
| 49 | | | | | | | | | | | 60 | 13,6 |
| 50 | | | | | | | | | | | 60 | 13,6 |
| 51 | | | | | | | | | | | 60 | 13,6 |
| 52 | | | | | | | | | | | 60 | 13,6 |
| 53 | | | | | | | | | | | 60 | 13,6 |
| 54 | | | | | | | | | | | 60 | 13,6 |
| 55 | | | | | | | | | | | | |
| 56 | | | | | | | | | | | 30 | 6,8 |
| 57 | | | | | | | | | | | 14 | 3,2 |

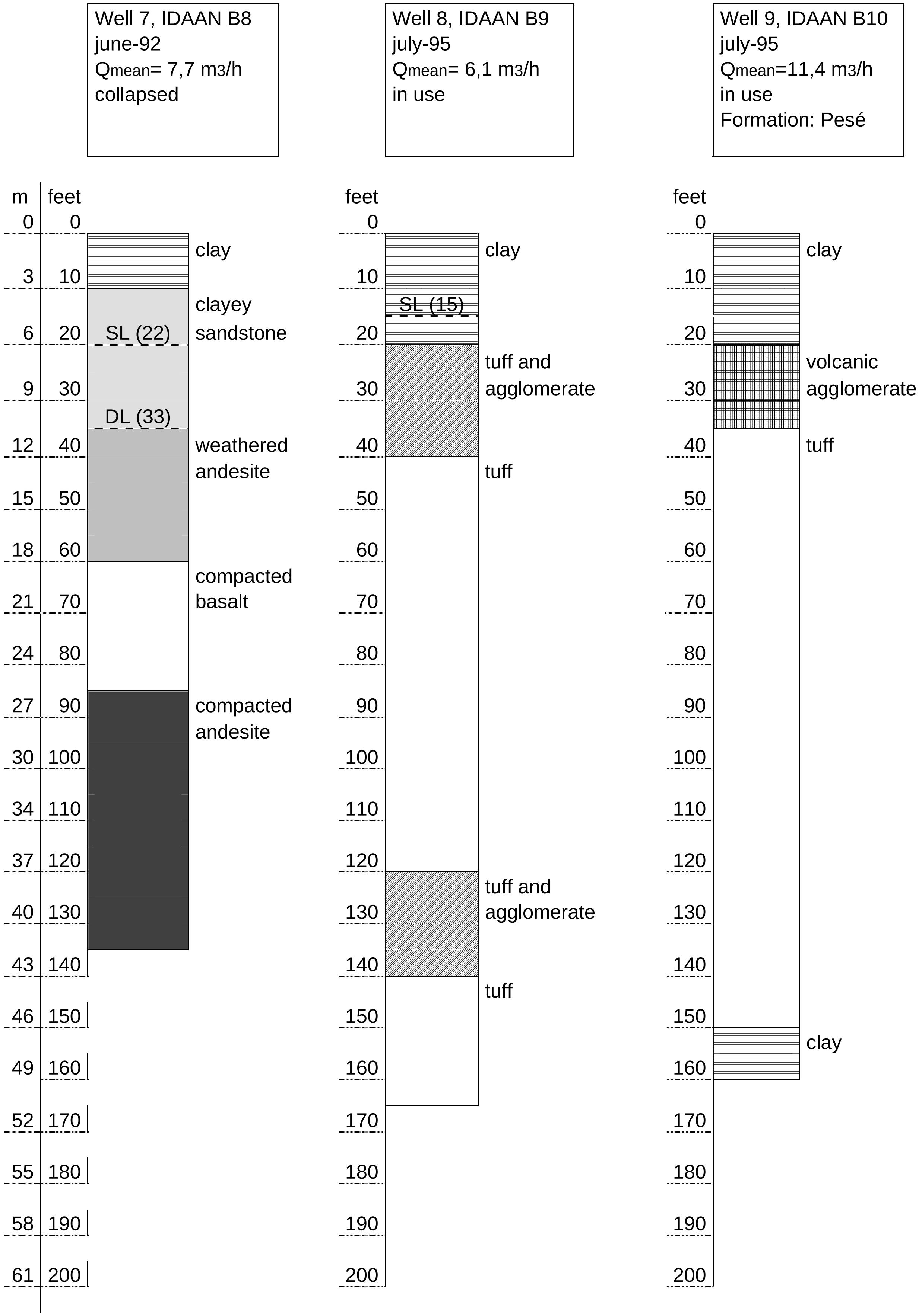
Database with wells from MIDA and ANAM.

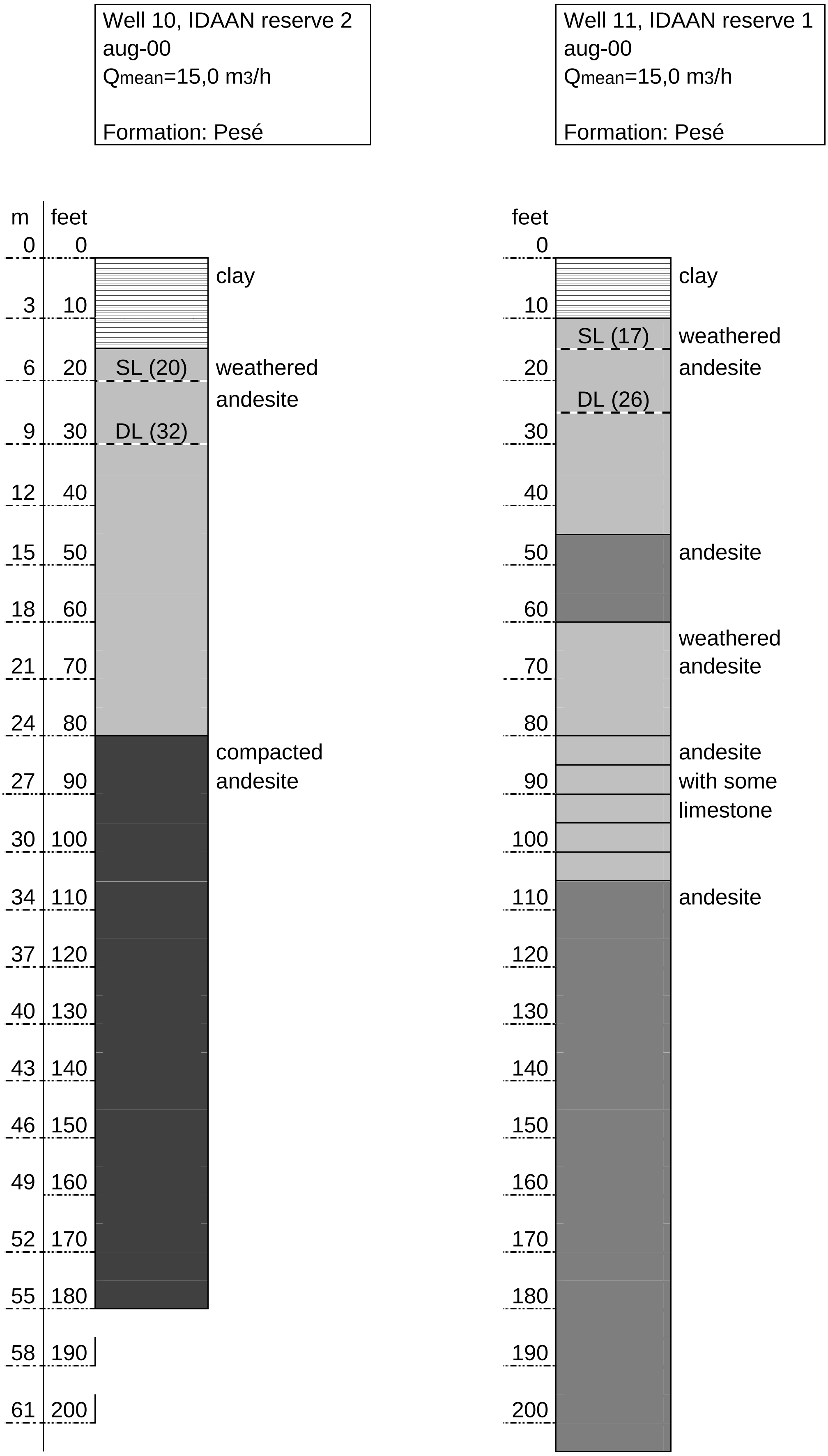
| | | | Work pattern | Wateruse | | | Soil |
|---|---|---|---|---|---|---|---|
| | Qneeded | | | summer, 182 days | winter, 182 days | Total | profile |
| | (gpm) | (m3/h) | | (m3/season) | (m3/season) | (m3/year) | (x=exist) |
| 23 | | | | | | | x |
| 24 | | | | | | | x |
| 25 | | | | | | | x |
| 26 | | 11.1 | during summer | 25116 | | 25116 | x |
| 27 | | | | | | | no |
| 28 | | | | | | | no |
| 29 | | | | | | | no |
| 30 | | | | | | | no |
| 31 | | | | | | | no |
| 32 | | | | | | | no |
| 33 | | 14.3 | during summer | 38294 | | 38294 | x |
| 34 | | | | | | | no |
| " | | 12,1 | during summer | 81752 | | 81752 | no |
| 35 | | | | | | | |
| 36 | | 8,7 | during summer | 31328 | | 31328 | x |
| 37 | | 7,9 | during summer | | | | |
| 38 | | 9,1 | during summer | 42446 | | 42446 | x |
| 39 | | | | | | | no |
| 40 | | | | | | | no |
| 41 | | | | | | | |
| 42 | | | | | | | |
| 43 | | | | | | | |
| 44 | | | | | | | |
| 45 | | | | | | | |
| 46 | | | | | | | |
| 47 | | | | | | | |
| | | | sum: | 218936 | | 218936 | |
| 48 | *60* | *13,6* | Automatic | 2067 | 2756 | 4823 | no |
| 49 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 50 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 51 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 52 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 53 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 54 | | 7,6 | 10h per day, 24 days per month | 13777 | 13777 | 27554 | no |
| 55 | | | | | | | no |
| 56 | | 6,8 | 14h per day, 365 days | 17361 | 17361 | 34722 | no |
| 57 | | 3,2 | 3h per day, 365 days | 8102 | 8102 | 16204 | no |
| | | | sum: | 110192 | 110881 | 221073 | |

| | Notes |
|---|---|
| | |
| | |
| 23 | The well collapsed. |
| 24 | No electricity yet. The well is not in the MIDA project. |
| 25 | |
| 26 | |
| 27 | In a garden in Pesé. Is not in use because of the low discharge. |
| 28 | |
| 29 | |
| 30 | Well 3-6 are sitiated very close to eachother, within an area of 40x40m2. |
| 31 | |
| 32 | collapsed |
| 33 | |
| 34 | |
| " | The same well as the one above but drilled again with a bigger diameter to get a higher discharge. |
| 35 | |
| 36 | |
| 37 | |
| 38 | |
| 39 | No electricity yet. The water is for cattle. |
| 40 | |
| 41 | |
| 42 | |
| 43 | |
| 44 | |
| 45 | |
| 46 | |
| 47 | |
| 48 | |
| 49 | |
| 50 | |
| 51 | |
| 52 | |
| 53 | |
| 54 | |
| 55 | |
| 56 | |
| 57 | |

## Appendix C1: Geological profiles of IDAAN wells.



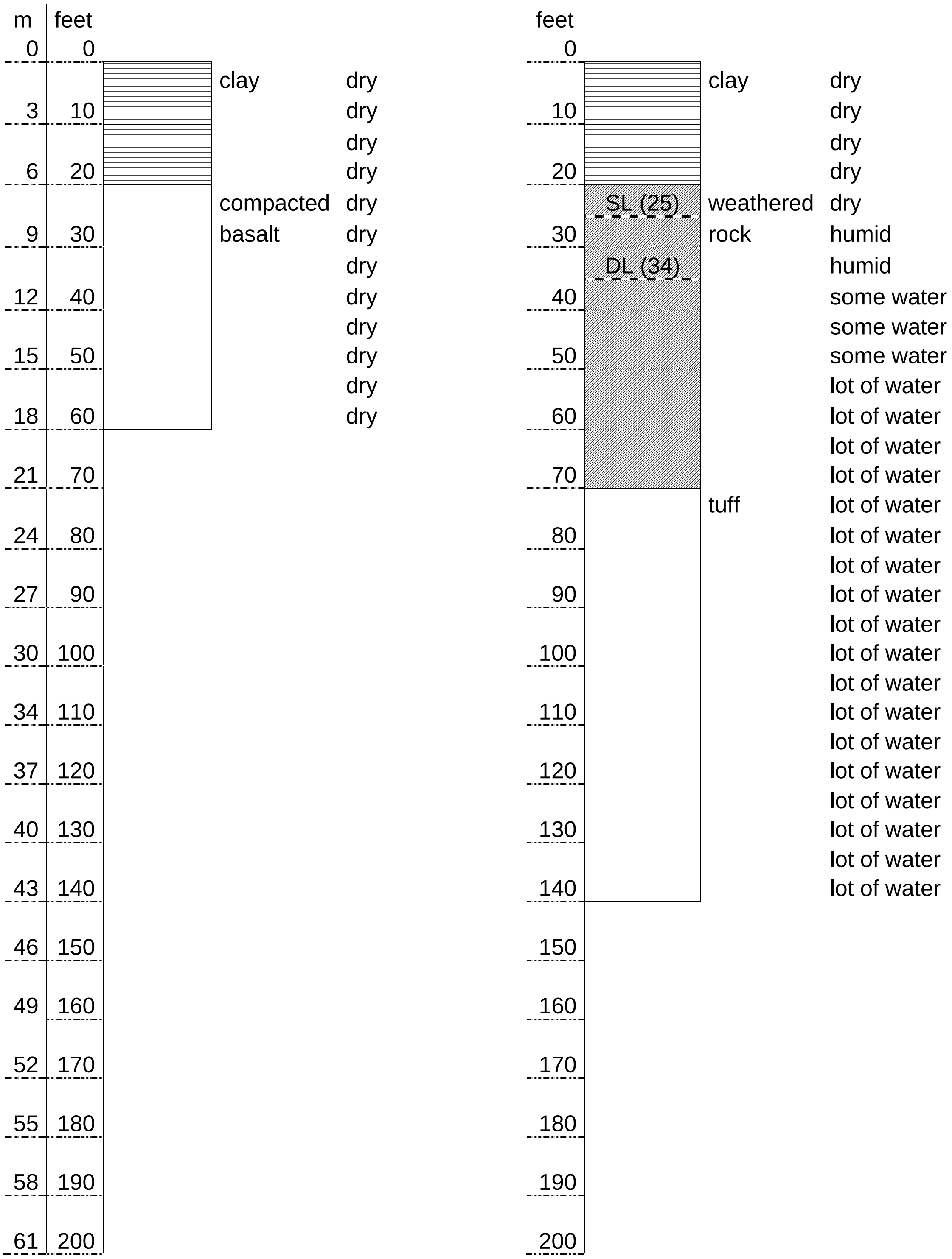

Well 7, IDAAN B8
june-92
Qmean= 7,7 m3/h
collapsed
Well 8, IDAAN B9
july-95
Qmean= 6,1 m3/h
in use
Well 9, IDAAN B10
july-95
Qmean=11,4 m3/h
in use
Formation: Pesé
m
feet
0 3 6 9 12 15 18 21 24 27 30 34 37 40 43 46 49 52 55 58 61
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
clay
clayey sandstone
SL (22)
DL (33)
weathered andesite
compacted basalt
compacted andesite
clay
SL (15)
tuff and agglomerate
tuff
tuff and agglomerate
tuff
clay
volcanic agglomerate
tuff
clay


Well 10, IDAAN reserve 2
aug-00
Qmean=15,0 m3/h
Formation: Pesé
Well 11, IDAAN reserve 1
aug-00
Qmean=15,0 m3/h
Formation: Pesé
m
feet
0
3
6
9
12
15
18
21
24
27
30
34
37
40
43
46
49
52
55
58
61
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
clay
SL (20)
DL (32)
weathered
andesite
compacted
andesite
clay
SL (17)
DL (26)
weathered
andesite
andesite
weathered
andesite
andesite
with some
limestone
andesite

# Appendix C2: Geological profiles of MIDA wells.

Well 23, MIDA
Carmen Esilda Ureña (1)
03-apr
no discharge, collapsed

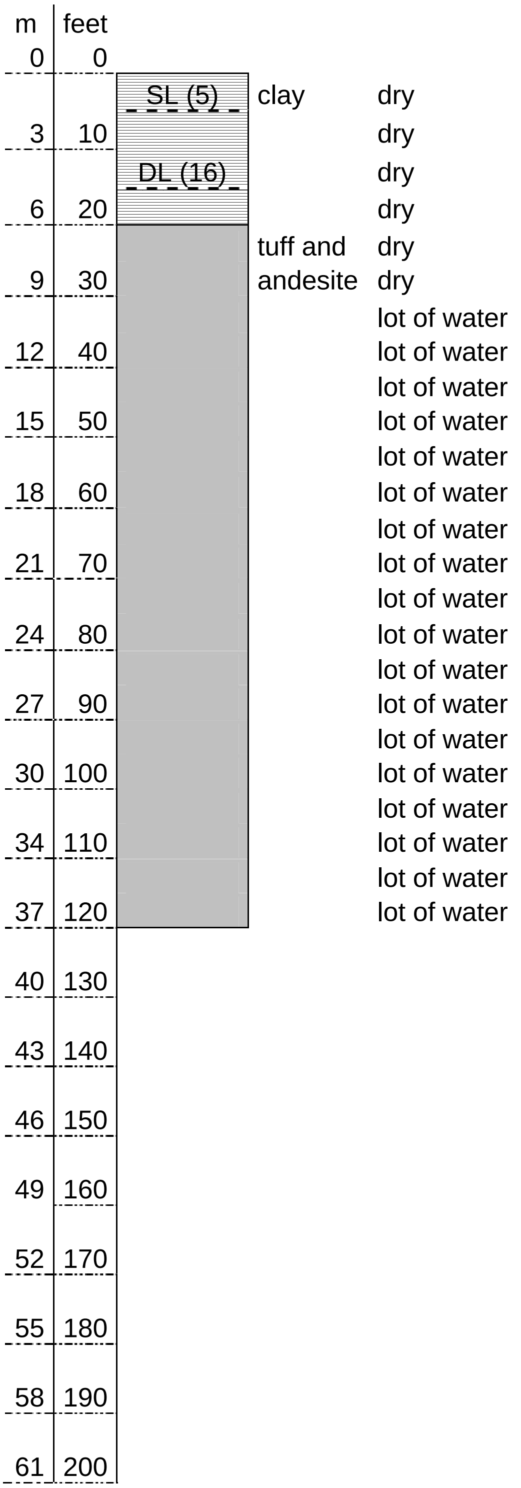
Well 24, MIDA
Carmen Esilda Ureña (2)
03-apr
$Q_{balance}$=20,4 $m^3/h$
not in use because no electricity



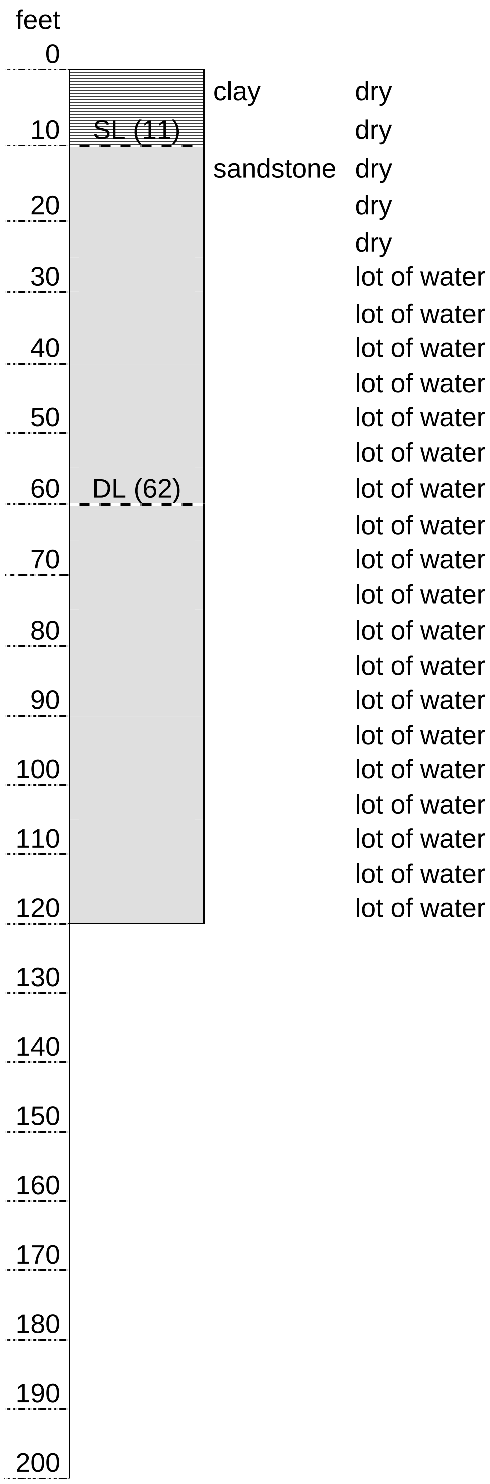
| Well 25, MIDA<br>Heriberto Varela (1)<br>02-nov<br>not enough discharge | Well 26, MIDA<br>Heriberto Varela (2)<br>02-nov<br>Qbalance=8,6 m3/h<br>in use |
|---|---|

| m | feet | Well 25 |  | feet | Well 26 |  |
|---|---|---|---|---|---|---|
| 0 | 0 |  |  | 0 |  |  |
|  |  | clay | dry |  | clay | humid |
| 3 | 10 |  | dry | 10 | SL (11) | humid |
|  |  |  | humid |  |  | dry |
| 6 | 20 |  | humid | 20 |  | dry |
|  |  |  | humid |  | tuff | some water |
| 9 | 30 |  | some water | 30 |  | some water |
|  |  | weathered rock | some water |  |  | some water |
| 12 | 40 | compact | some water | 40 |  | some water |
|  |  | andesite | some water |  |  | some water |
| 15 | 50 |  | some water | 50 |  | some water |
|  |  |  | some water |  |  | some water |
| 18 | 60 |  | some water | 60 |  | some water |
|  |  |  | some water |  |  | some water |
| 21 | 70 |  | some water | 70 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 24 | 80 |  | some water | 80 | DL (80) | lot of water |
|  |  |  | some water |  |  | lot of water |
| 27 | 90 |  | some water | 90 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 30 | 100 |  | some water | 100 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 34 | 110 |  | some water | 110 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 37 | 120 |  | some water | 120 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 40 | 130 |  | some water | 130 |  | lot of water |
|  |  |  | some water |  |  | lot of water |
| 43 | 140 |  | some water | 140 |  | lot of water |
|  |  |  |  |  |  | lot of water |
| 46 | 150 |  |  | 150 |  |  |
| 49 | 160 |  |  | 160 |  |  |
| 52 | 170 |  |  | 170 |  |  |
| 55 | 180 |  |  | 180 |  |  |
| 58 | 190 |  |  | 190 |  |  |
| 61 | 200 |  |  | 200 |  |  |

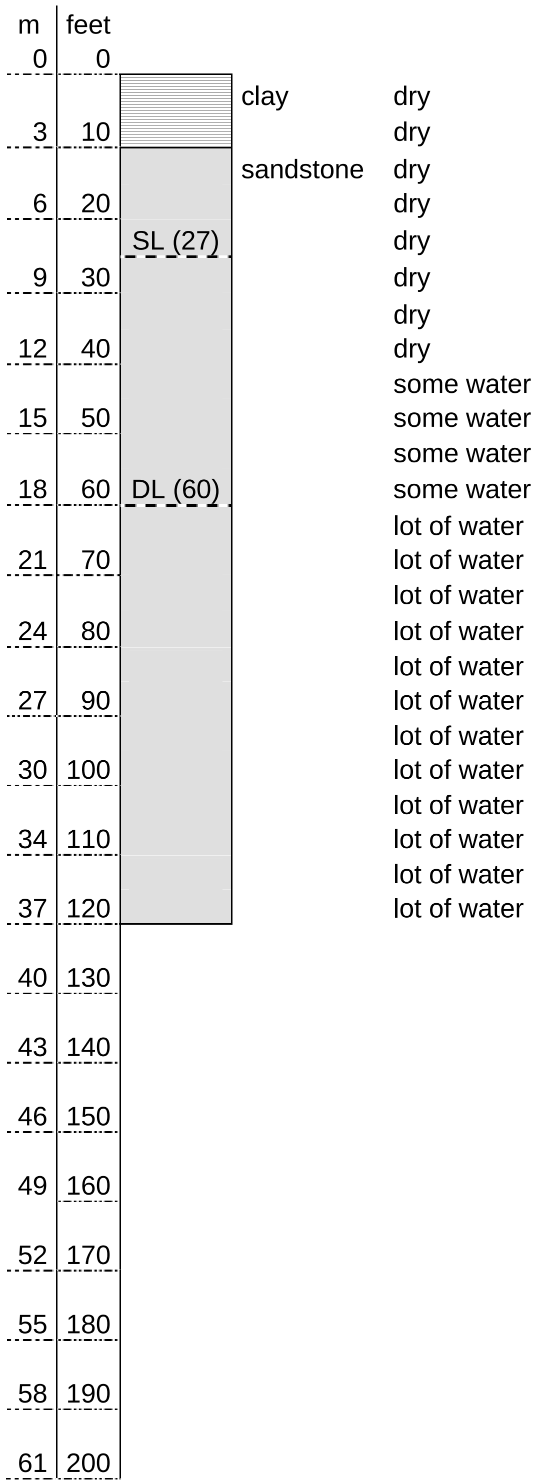
Well 33, MIDA
Reyes Solis (6)
01-dec
$Q_{balance}$=8,6 m3/h
in use




Well 36, MIDA
Gabriel Mudarra (2)
02-aug
$Q_{balance}$=9,1 m3/h
in use



Well 38, MIDA
Abelina de Rodriguez (Tahal)
02-aug
$Q_{balance}$=9,1 $m^3$/h
in use



# Appendix D: Measured static and dynamic values from field study, October 2003.

| Authority | | Community/Owner/ | Well no | In use | Static | | | Dynamic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Factory | | | stand by time | level | date | working time* | level | discharge | | date |
| | | | | (x=yes) | (h) | (m) | | (h) | (m) | (gpm) | (m3/h) | |
| IDAAN | 1 | Pesé | B1 | x | 18 | 6,3 | 24-okt-03 | 25 h 30 min | 8,0 | 32 | 7,3 | 23-okt-03 |
| | 2 | Pesé | B3 | x | 2 h 45 min | 7 | 24-okt-03 | 24 | 8,7 | 56 | 12,7 | 24-okt-03 |
| | 3 | Pesé | B4 | no | | 5,2 | 23-okt-03 | | | | | |
| | 4 | Pesé | B5 | no | | 9,8 | 23-okt-03 | | | | | |
| | 5 | Pesé | B6 | x | 11 | 1,4 | 24-okt-03 | 8 | 2,9 | 83 | 18,9 | 24-okt-03 |
| | 6 | Pesé | B7 | x | 17 h 30 min | 3,7 | 24-okt-03 | 26 | 6,2 | 40 | 9,1 | 23-okt-03 |
| | 7 | Pesé | B8 | no | | 2,7 | | | | | | |
| | 8 | Pesé | B9 | x | 2 h 30 min | 3,2 | 24-okt-03 | 24 | 6,0 | 32 | 7,3 | 24-okt-03 |
| | 9 | Pesé | B10 | x | 11 h 30 min | 1,1 | 24-okt-03 | 8 h 30 min | 2,6 | 40 | 9,1 | 24-okt-03 |
| MINSA | 14 | Arenita | 2 | x | 1 h 45 min | 0,8 | 31-okt-03 | | | *40* | 9,1 | |
| | 15 | Bulungo de La Arenita | 1 | x | 16 h 30 min | 1,7 | 31-okt-03 | 2 h 20 min | 5,20 | *40* | 9,1 | 31-okt-03 |
| | 16 | Bulungo de La Arenita | 2 | x(summer) | since summer | 1,4 | 31-okt-03 | | | *30* | 6,8 | |
| | 17 | Barriada Las Cabras | 1a | x | | | | automatic | 3,45 | *40* | 9,1 | 31-okt-03 |
| | 19 | Las Cabras | 1 | x | | | | | 1,90 | *60* | 13,6 | 31-okt-03 |
| | 20 | Las Cabras | 2 | x(summer) | since summer | 2,1 | 31-okt-03 | | | *30* | 6,8 | |
| | 21 | Sabana Grande | 1 | x | 5 h | 0,5 | 31-okt-03 | | | *60* | 13,6 | |
| | 22 | Sabana Grande | 2 | x | 2 h 15 min | 1,3 | 31-okt-03 | | | *60* | 13,6 | |

*italics = Info said by Genaro Marciaga, responsible for the MINSA wells in the area, or by the operator.*

| Authority | | Comunity/Owner/ Factory | Well no | In use (x=yes) | Static: stand by time (h) | Static: level (m) | Static: date | Dynamic: workingtime* (h) | Dynamic: level (m) | Dynamic: discharge (gpm) | Dynamic: discharge (m3/h) | Dynamic: date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIDA | 24 | Carmen Esilda Ureña | 2 (no electricity) | no | | 5,0 | 22-okt-03 | | | | | |
| | 27 | Mario Argona | 1 | x(summer) | | 5,1 | 22-okt-03 | | | | | |
| | 33 | Reyes Solis | 6 | x(summer) | | 1,6 | 22-okt-03 | | | | | |
| | " | Irwin Osorio | (redrilled) | x(summer) | | 2,5 | 22-okt-03 | | | | | |
| | 36 | Gabriel Mudarra | 2 | x(summer) | | 1,0 | 22-okt-03 | | | | | |
| | 37 | Abelina de Rodríguez | (Equipado) | x(summer) | | 3,8 | 22-okt-03 | | | | | |
| | 38 | Abelina de Rodríguez | (Tahal) | x(summer) | | 5,4 | 22-okt-03 | | | | | |
| | 39 | Juan Cedeño | (no electricity) | no | | 1,1 | 22-okt-03 | | | | | |
| | 40 | Ulbino Rodríguez | 1 | no | | 1,0 | 22-okt-03 | | | | | |
| | 42 | Miguel Coba | 2 | no | | 1,5 | 30-okt-03 | | | | | |
| ANAM | 48 | 1. Liquor fabric | 1 | x | | | | Enough | 7,2 | *60* | 13,6 | 31-okt-03 |

*italics = Info said by Genaro Marciaga, responsible for the MINSA wells in the area, or by the operator.*

# Appendix E: Water use in Pesé stream area.

**IDAAN, Pesé village**

| Community | well No. | in use | discharge | discharge | Work pattern | Working hours | Water consumption |
|---|---|---|---|---|---|---|---|
| | | | | | | per day | m3 per day |
| | | (x=yes) | (gpm) | (m3/h) | | (24 hours) | (m3/24 hours) |
| Pesé | B1 | x | 32 | 7,3 | Work 30 hours, rest 18 hours. | 15 | 109 |
| Pesé | B3 | x | 56 | 12,7 | Work 30 hours, rest 18 hours | 15 | 191 |
| Pesé | B6 | x | 83 | 18,9 | 6-18 every day | 12 | 226 |
| Pesé | B7 | x | 40 | 9,1 | Work 30 hours, rest 18 hours | 15 | 136 |
| Pesé | B9 | x | 32 | 7,3 | Work 30 hours, rest 18 hours | 15 | 109 |
| Pesé | B10 | x | 40 | 9,1 | 6-18 every day | 12 | 109 |

| | | |
|---|---|---|
| Total consumption: | 880 | (m3/day) |
| Total consumption per year: | 321321 | (m3/year) |
| People in Pesé ca: | 2600 | inh. |
| Consumption per person and year: | 124 | (m3/year) |

1 gallon = 3.7854 (dm3)

# Water use in smaller communities and irrigation in Pesé stream area.

**MINSA, In the countryside in the project area**

| Community | well No. | in use (x=yes) | Houses in community (n) | People in community (n) | Water consumption (m3/year) |
|---|---|---|---|---|---|
| Cascajalillo | 1 | x | *43* | 172 | 21328 |
| Arenita | 1 (manual) | no | *54* | 216 | 26784 |
| Arenita | 2 | x | *"* | | |
| Bulungo de La Arenita | 1 | x | *31* | 124 | 15376 |
| Bulungo de La Arenita | 2 | x(summer) | *"* | | |
| Barriada Las Cabras | 1a | x | *40* | 160 | 19840 |
| Barriada Las Cabras | 1b | no | *"* | | |
| Las Cabras | 1 | x | *103* | 412 | 51088 |
| Las Cabras | 2 | x(summer) | *"* | | |
| Sabana Grande | 1 | x | *85* | 340 | 42160 |
| Sabana Grande | 2 | x | *82* | 328 | 40672 |
| | | | Water consumption in total: | | 217248 (m3/year) |

**MIDA, Irrigation**

| Owner | In use (x=yes) | Irrigation area (ha) | Water consumption (m3/year) |
|---|---|---|---|
| Heriberto Varela | x | 3 | 25116 |
| Reyes Solis | x | 5 | 38 294 |
| Irwin Osorio | x | 10 | 81 753 |
| Gabriel Mudarra | x | 4 | 31328 |
| Avelina de Rodríguez | x | 5,07 | 42446 |
| | | Total water use: | 218936 (m3/year) |

Irrgation is used during the dry period, approx. 182 days per year.

# Water use by the industries in the Pesé stream area

**ANAM, Industries**

| **Industries** | **Well no** | **in use** | **Water use** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **(x=yes)** | **summer, 182 days** | | **winter, 182 days** | | | **per year** | **Qmean** | **Qmean** |
| | | | **(m3/day)** | **(m3/period)** | **(m3/day)** | **(m3/period)** | | **(m3/year)** | **(gpm)** | **(m3/s)** |
| 1. Liquor fabric | 7(with MIDA) | x | *11* | 2067 | *15* | 2756 | | 4823 | | |
| | | | | | | | | | | |
| 2. Liquor fabric | 1 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | 2 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | 3 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | 4 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | 5 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | 6 | x | 76 | 13777 | 76 | 13777 | | 27555 | 60 | 0,0038 |
| | | | | | | | | | | |
| 3. Pork breeding | 1 | x | 95 | 17361 | 95 | 17361 | | 34723 | 30 | 0,0019 |
| | 2 | x | 45 | 8102 | 45 | 8102 | | 16204 | 14 | 0,0009 |

| | Factory: | | | | | | |
|---|---|---|---|---|---|---|---|
| Water use in total per factory: | 1 | 2067 | (m3/period) | 2756 | (m3/period) | 4823 | (m3/year) |
| | 2 | 82664 | (m3/period) | 82664 | (m3/period) | 165329 | (m3/year) |
| | 3 | 25463 | (m3/period) | 25463 | (m3/period) | 50927 | (m3/year) |
| Water use in total: | | 110195 | (m3/period) | 110883 | (m3/period) | 221078 | (m3/year) |

# Appendix F: Water supply for the Pesé stream area,

from the aquifers, extrapolated from Rio La Villa watershed.

*Table 1*

**Precipitation five dry years in Rio La Villa**

| Year with low prec. | Precipitation (mm/year) |
|---|---|
| 1976 | 1321 |
| 1983 | 1641 |
| 1987 | 1701 |
| 1991 | 1582 |
| 1992 | 1690 |

*Table 2*

**Discharge in Atalayita,Rio la Villa, the dry months of five dry years and the average of the discharge per year**

| Dry months\Year | 1977 (m3/s/month) | 1984 (m3/s/month) | 1988 (m3/s/month) | 1992 (m3/s/month) | 1993 (m3/s/month) |
|---|---|---|---|---|---|
| January | 7,52 | 13,6 | 8,62 | 7,37 | 9,9 |
| February | 6,02 | 8,39 | 4,76 | 4,84 | 4,48 |
| March | 3,31 | 6,12 | 3,13 | 4,04 | 2,95 |
| April | 2,94 | 5,26 | 2,39 | 3,58 | 4,77 |
| Average | 4,95 | 8,34 | 4,73 | 4,96 | 5,53 |

*Table 3*

**Basic flow in Atalayita,Rio la Villa during the dry period applied on the whole year five dry years and then extrapolated to Pesé .**

| Year meas. flow | Q (m3/s/dry month) | V La Villa (m3/dry month) | V La Villa (m3/year) | A tot (m2) | h (m/year) | A Pesé (m2) | V Pesé (m3/year) |
|---|---|---|---|---|---|---|---|
| 1977 | 4,95 | 12823920 | 153887040 | 750000000 | 0,205 | 44930000 | 9218860 |
| 1984 | 8,34 | 21623760 | 259485120 | 750000000 | 0,346 | 44930000 | 15544889 |
| 1988 | 4,73 | 12247200 | 146966400 | 750000000 | 0,196 | 44930000 | 8804267 |
| 1992 | 4,96 | 12849840 | 154198080 | 750000000 | 0,206 | 44930000 | 9237493 |
| 1993 | 5,53 | 14320800 | 171849600 | 750000000 | 0,229 | 44930000 | 10294937 |
| | | | | | | Average: | 10620089 |

dry months = January-April, 1 month = 30 days

# Appendix G: Physical and chemical analyses from wells in Pesé village, IDAAN.

Pesé, IDAAN, year 1999, May (dry period)

| | Well | pH | Cond. | Alk. | Ca | Mg | Hardness | | Cl | $NO_3^-$ | $NO_2^-$ | $SO_4^{2-}$ | Cu | Fe | F | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no. | name | | mS/m | mg/l | mg/l | mg/l | mg/l | °dH | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FNU |
| 1 | B1 | **6,8** | 55 | 290 | **180** | **70** | 296 | **41** | 48 | **5,9** | **0,3** | 28 | - | 0,01 | - | 0,15 |
| 2 | B3 | **6,8** | 60 | 332 | **178** | **98** | 340 | **48** | 49 | 6 | - | 25 | - | 0,01 | - | 0,15 |
| 3 | B4 | **7,0** | 56 | 298 | **180** | **76** | 305 | **43** | 47 | 3,6 | - | 26 | - | 0,05 | - | 0,2 |
| 4 | B5 | **7,4** | 40 | 246 | **132** | **72** | 251 | **35** | 21 | 3,1 | - | 0 | - | 0,01 | - | 0,15 |
| 5 | B6 | **7,2** | 60 | 314 | **190** | **90** | 339 | **47** | 51 | 4,5 | - | 33 | - | 0,01 | - | 0,2 |
| 6 | B7 | **7,5** | 37 | 228 | **108** | **70** | 224 | **31** | 28 | 2,8 | - | 0 | - | 0,01 | - | 0,15 |
| 8 | B9 | **7,2** | 39 | 226 | **120** | **60** | 219 | **31** | 29 | 3,8 | - | 12 | - | 0,01 | - | 0,2 |
| 9 | B10 | **7,2** | 47 | 270 | **140** | **80** | 272 | **38** | 34 | 4,1 | - | 9 | - | 0,01 | - | 0,2 |
| Threshold value | | 7,5-9,0 | - | - | 100 | 30 | | 15 | 100 | 5 | 0,05 | 100 | 0,05 | 0,1 | 1,3 | 0,5 |

Pesé, IDAAN, year 2000, September (rainy period)

| | Well | pH | Cond. | Alk. | Ca | Mg | Hardness | | Cl | $NO_3^-$ | $NO_2^-$ | $SO_4^{2-}$ | Cu | Fe | F | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no. | name | | mS/m | mg/l | mg/l | mg/l | mg/l | °dH | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FNU |
| 1 | B1 | **7,4** | 55 | 232 | **180** | **94** | 335 | **47** | 27 | 3 | 0 | 3 | 0,01 | 0,01 | 0,1 | **0,7** |
| 2 | B3 | **7,2** | 86 | 292 | **250** | **120** | 448 | **63** | 59 | 1 | **1** | 0 | 0,04 | 0,00 | 0,0 | **0,86** |
| 3 | B4 | **7,4** | 54 | 236 | **166** | **70** | 282 | **39** | 27 | 1 | **1** | 1 | 0,04 | 0,05 | 0,2 | **0,95** |
| 4 | B5 | **7,4** | 43 | 208 | **162** | **68** | 274 | **38** | 21 | 1,4 | 0 | 8 | **0,05** | 0,00 | 0,1 | **0,62** |
| 5 | B6 | **7,2** | 48 | 200 | **156** | **84** | 295 | **41** | 23 | 3,1 | **1** | 35 | **0,07** | 0,02 | 0,1 | **0,89** |
| 6 | B7 | **7,4** | 63 | 290 | **210** | **110** | 392 | **55** | 29 | 0 | 0 | 1 | **0,07** | 0,03 | 0,1 | **0,99** |
| 8 | B9 | **7,4** | 86 | 296 | **112** | **54** | 201 | **28** | 41 | 2,7 | 0 | 11 | 0,04 | 0,00 | 0,2 | **0,88** |
| 9 | B10 | **7,4** | 60 | 266 | **136** | **66** | 245 | **34** | 35 | 4,2 | 0 | 15 | **0,15** | 0,01 | 0,0 | **0,9** |
| Threshold value | | 7,5-9,0 | - | - | 100 | 30 | | 15 | 100 | 5 | 0,05 | 100 | 0,05 | 0,1 | 1,3 | 0,5 |

Pesé, IDAAN, year 2001, September (rainy period)

| | Well | pH | Cond. | Alk. | Ca | Mg | Hardness | | Cl | $NO_3^-$ | $NO_2^-$ | $SO_4^{2-}$ | Cu | Fe | F | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no. | name | | mS/m | mg/l | mg/l | mg/l | mg/l | °dH | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FNU |
| 1 | B1 | **7,2** | 60 | 200 | **170** | **132** | 388 | **54** | 31 | 2,4 | 0 | 5 | 0,01 | 0,01 | 0 | **0,6** |
| 2 | B3 | **7,4** | 83 | 312 | **238** | **122** | 439 | **62** | 69 | 0,8 | **1** | 2 | 0,02 | 0,02 | 0 | **0,5** |
| 3 | B4 | **7,2** | 61 | 242 | **146** | **74** | 268 | **38** | 33 | 1,8 | 0 | 3 | **0,06** | 0,06 | 0,1 | **0,7** |
| 4 | B5 | **7** | 42 | 194 | **140** | **72** | 259 | **36** | 21 | 2,8 | **1** | 12 | 0,01 | 0,02 | 0 | **0,7** |
| 5 | B6 | **7,4** | 50 | 214 | **176** | **90** | 325 | **45** | 35 | 1,2 | **1** | 39 | 0,03 | 0,03 | 0,2 | **0,5** |
| 6 | B7 | **7,2** | 65 | 306 | **172** | **140** | 403 | **56** | 33 | 0,3 | 0 | 4 | **0,08** | 0,08 | 0,1 | **0,8** |
| 8 | B9 | **7,2** | 91 | 284 | **126** | **60** | 225 | **31** | 53 | 0,2 | **1** | 18 | 0,01 | **0,16** | 0,2 | **0,6** |
| 9 | B10 | **7,4** | 65 | 278 | **146** | **76** | 271 | **38** | 37 | 0,6 | 0 | 21 | **0,08** | 0,08 | 0,1 | **0,6** |
| Threshold value | | 7,5-9,0 | - | - | 100 | 30 | | 15 | 100 | 5 | 0,05 | 100 | 0,05 | 0,10 | 1,3 | 0,5 |

Pesé, IDAAN,Year 2002

| | Well | pH | Cond. | Alk. | Ca | Mg | Hardness | | Cl | $NO_3^-$ | $NO_2^-$ | $SO_4^{2-}$ | Cu | Fe | F | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no. | name | | mS/m | mg/l | mg/l | mg/l | mg/l | °dH | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | FNU |
| 1 | B1 | **7,3** | 61 | 270 | **174** | **86** | 316 | **44** | 39 | 3 | **0,09** | 13 | **0,11** | 0,09 | 0 | **0,6** |
| 2 | B3 | **7,2** | 89 | 312 | **212** | **124** | 417 | **58** | 79 | 3,5 | **0,1** | 28 | **0,17** | 0,06 | 0,1 | **0,5** |
| 3 | B4 | **7,2** | 45 | 220 | **128** | **74** | 250 | **35** | 27 | 1,1 | **0,3** | 3 | **0,1** | 0,05 | 0 | **0,5** |
| 4 | B5 | **7,4** | 66 | 286 | **192** | **88** | 337 | **47** | 41 | 2,8 | **0,1** | 19 | **0,35** | 0,07 | 0,3 | **0,7** |
| 5 | B6 | **7,3** | 79 | 302 | **320** | **112** | 505 | **71** | 53 | 3,7 | **0,1** | 27 | **0,59** | 0,09 | 0,1 | **0,5** |
| 6 | B7 | **7,1** | 63 | 236 | **190** | **94** | 345 | **48** | 52 | 1,5 | **0,12** | 2 | **0,17** | 0,07 | 0 | **0,6** |
| 8 | B9 | **7,2** | 52 | 244 | **163** | **86** | 305 | **43** | 31 | 1,4 | **0,14** | 12 | **0,16** | 0,05 | 0,1 | **0,5** |
| 9 | B10 | **7,3** | 68 | 286 | **208** | **114** | 396 | **55** | 39 | 3,4 | **0,1** | 18 | **0,28** | 0,09 | 0,2 | **0,7** |
| Threshold value | | 7,5-9,0 | - | - | 100 | 30 | | 15 | 100 | 5 | 0,05 | 100 | 0,05 | 0,10 | 1,3 | 0,5 |

## Appendix H: Bacteriological analyses in Pesé village, IDAAN.

Bacteriological tests of the water from the wells and the pipe once a month year 2000.

2000

| Well no. | Well name | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | B1 | N | N | N | N | N | N | N | P1 | N | N | N | N |
| 2 | B3 | N | N | N | N | N | N | N | N | N | N | N | N |
| 3 | B4 | N | N | N | N | N | N | N | N | N | N | N | N |
| 4 | B5 | N | N | N | N | N | N | N | P1 | N | N | N | N |
| 5 | B6 | N | N | N | N | N | N | N | N | N | N | N | N |
| 6 | B7 | N | N | N | N | N | N | N | N | N | N | N | N |
| 8 | B9* | P2 | P2 | P2 | N | N | N | P1 | N | N | N | N | N |
| 9 | B10 | N | N | N | N | N | N | N | N | N | N | N | N |
| | R1 | 3N | 4N | 4N | 4N | 6N | 4N | 6N | 5N | 7N | 9N | 9N | 7N |

R1 = The pipe system

N = no contamination of bacteria in a water sample of 100 ml.
P1= 1-10 E-coli bacteria in 100 ml water sample.
P2= 10-100 E-coli bacteria in 100 ml water sample.
P3 = 100-1000 E-coli bacteria in 100 ml water sample.

* Without addition of chlorine

Bacteriological tests of the water from the wells and the pipe once a month year 2003.
2003

| Well no. | Well name | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | B1 | P1 | N | N | N | N | N | N | P1 | N | | | |
| 2 | B3 | P1 | N | N | N | N | N | N | N | N | | | |
| 3 | B4 | N | N | N | P1 | P1 | N | N | N | N | | | |
| 4 | B5 | P1 | N | N | N | N | N | N | - | N | | | |
| 5 | B6 | N | N | N | N | N | P2 | N | N | N | | | |
| 6 | B7 | N | N | N | N | N | N | N | N | N | | | |
| 8 | B9* | P3 | P2 | P2 | P1 | P1 | P2 | N | P2 | P2 | | | |
| 9 | B10 | N | N | N | N | N | P2 | N | N | N | | | |
| | R1 | P1, 7N | 11N | 11N | 6N | 6N | 9N | P1, N | 2P1, 13N | 4P1, 7N | | | |

R1 = The pipe system

N = no contamination of bacteria in a water sample of 100 ml.
P1= 1-10 E-coli bacteria in 100 ml water sample.
P2= 10-100 E-coli bacteria in 100 ml water sample.
P3 = 100-1000 E-coli bacteria in 100 ml water sample.

* Without addition of chlorine