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# THE MEASUREMENT OF THE INFILTRATION OF THE SOILS OF THE ALTA CUENCA DEL GUADALQUIVIR, TARIJA, BOLIVIA

Villena Martínez, Esteban Manuel [(1)]; Torregrosa López, Juan Ignacio [(1)]; Lo Iacono Ferreira, Vanesa [(1)]; Stolpa, David [(2)]

[(1)] Universitat Politècnica de València, [(2)] Universidad Católica Boliviana

Usually two considerations are defined to determine the elements of a water balance model. The first consideration includes the spatial limit conditions and the second the period of time. Both influence the reliability of the model and its results. The Model is also influenced by the availability of hydrometeorological data, the objectives of the study and hydrological abstractions that establish the degree of precipitation reduction. One of them is the infiltration that determines the amount of water that enters the soil and how much it drains superficially.

The lack of infiltration data is a problem to develop a water balance model in the upper basin of the Guadalquivir river in Tarija, Bolivia; the region is considered semi-arid and with short storms. The soils in the basin are shallow above the highly contorted bedrock in the surrounding hills and mountains, with deep lacustrine soils and glacial deposits.

This work studies the case of the upper basin of the Guadalquivir river. Describe the preliminary steps and the results in the development of infiltration data in a short period of time. These data will serve as the basis for hydrological and cartographic studies of the area.

***Keywords:*** *Hydric balance; hydrological abstractions; infiltration*

# LA MEDICIÓN DE LA INFILTRACIÓN DE LOS SUELOS DE LA ALTA CUENCA DEL GUADALQUIVIR, TARIJA, BOLIVIA

Habitualmente se definen dos consideraciones para determinar los elementos de un modelo de balance hídrico. La primera consideración incluye las condiciones de límite espacial y, la segunda, el período de tiempo. Ambas influyen en la fiabilidad del modelo y sus resultados. Además, el modelo se ve influenciado por la disponibilidad de datos hidrometeorológicos, los objetivos del estudio y las abstracciones hidrológicas que establecen el grado de reducción de la precipitación. Una de ellas es la infiltración que determina la cantidad de agua que penetra al suelo y cuanto finalmente escurre superficialmente.

La falta de datos de infiltración es un problema para desarrollar un modelo de balance hídrico en la alta cuenca del Guadalquivir en Tarija, Bolivia; la región se considera semi-árida y con tormentas de duración corta. Los suelos en la cuenca son poco profundos sobre la roca madre altamente contorsionada en las colinas y montañas circundantes, presenta suelos lacustres profundos y depósitos glaciales.

Este trabajo estudia el caso de la cuenca alta del río Guadalquivir. Describe los pasos preliminares y los resultados en el desarrollo de los datos de la infiltración en un corto período de tiempo. Estos datos servirán de base para estudios hidrológicos y cartográficos del área.

***Palabras clave:*** *Balance hídrico; abstracciones hidrológicas; infiltración*

Correspondencia: Vanesa Lo Iacono Ferreira valoia@upv.es

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## 1. Introduction

The study of the water balance in watersheds is based on the application of the principle of mass balance, which establishes that for any arbitrary volume and during any period of time, the difference between the inputs and outputs will be conditioned by the variation of the volume of water stored (UNESCO, 1981). The factors influencing the water balance are defined as meteorological parameters such as precipitation, temperature, solar radiation, wind, etc., geophysical parameters such as the soil cover and slope, and soil characteristics such as texture and soil infiltration rates (C. Alvarado & M. Barahoma-Palomo, 2017).

The structure of the soils can describe the disposition of the solid part and the spaces or porous ones between them (Marshall & Holmes, 1979). The empty spaces or pores between the grains of the soil allow the water to flow through them, allowing to determine the amount of water infiltrated between it (Das, B.M., 2004). Infiltration is a key process in the areas of hydrology, agricultural and civil engineering, irrigation design and soil and water conservation. It is complex, depending on the soil drop properties and initial and contour conditions within the flow domain (Assouline, S., 2013). Horton R.E., (1940) defines the infiltration capacity as the maximum rate at which a soil under certain conditions absorbs the rain that falls and varies over time, especially during the initial period of the rain, reaching at the end, a minimum capacity of Infiltration. It also notes that the rate of infiltration depends on the conditions of the soil surface, while other authors such as Parr J.F. & Bertrand A.R. (1960) indicate that the infiltration depends on the soil mass, regardless of the surface conditions.

Knowledge of the mechanisms of movement of water in the superficial horizons of the soil occupies a dominating place in many areas of research, such as agronomy, civil engineering, Hydrology and environmental Sciences (Filgueira R., et al., 2006). Sihag, P. Tiwari, N.K., & Ranjan S., (2017), indicate that one of the tasks of water management is to calculate and control it. Consequently, these processes depend on the hydraulic conductivity of the soil to be determined in the field or in the laboratory.

The hydraulic conductivity of the soil indicates how quickly water is infiltrated when applied to the soil surface. needs to be found in various applications, including assessment of groundwater recharge and surface runoff; And in the prediction of erosion and soil compaction. Therefore, it is important to obtain the in situ values of the hydraulic conductivity of the soil (M. Fatehnia, K. Tawfig & T. Abichou, 2014).

While Lakzian et al. (2010), Emami et al. (2012), Kaikhajesh et al. (2012) & Fereshte, (2014) indicate that the direct measurement of the hydraulic conductivity of the soil is difficult, expensive and that it also requires a lot of work and time; Kargas G., et al., (2018) points out that disk infiltrometers, among other experimental apparatus used in situ, have been widely used in recent decades and allow to know the hydraulic behavior of the soil and the sorptivity of the upper layers as factors essential in hydrological modeling.

The stress-infiltration method is based on the application of water to the constant negative pressure head known on the soil surface through a porous disc. When the disc is in contact with the surface of the ground, the water flows from the water tank to the pores. The water level in the reservoirs of the disk Infiltrometers is often visually controlled by the operator (V. Klípa, V., Sněhota M., & Dohnal, M. 2015).

Flow through unsaturated soil is more complicated than flow through spaces of continuously saturated pores. The macro pores are usually filled with air, leaving only the fine pores to accommodate the movement of the water. Therefore, the hydraulic conductivity of the soil depends to a large extent on the detailed geometry of the pores, the water content and the differences in the potential of the matrix. (Rose, C.W.,1966, Brady N.C. & Weil, R.R. 1999).

The infiltration rate expressed as inches per hour or centimeters per hour is the rate at which the water enters the soil on the surface. If water is flooded on the surface the infiltration occurs at the potential infiltration rate, for example rain infiltration, is less than the potential infiltration rate, then the actual infiltration rate will also be less than the potential rate (Chow V. T., Maidment D.R., & Mays L.W., 1994).

Most of the infiltration equations describe the potential rate. The accumulated infiltration ***F*** is the accumulated depth of infiltrated water within a given period and is equal to the integral of the infiltration rate during that period (Chow V.T., Maidment D.R., & Mays L.W., 1994).

$$F(t) = \int_0^t f(\tau)d(\tau) \tag{1}$$

Donde:

τ = v auxiliary time variable

Conversely, the infiltration rate is the temporal derivative of accumulated infiltration (Chow V.T., Maidment D.R., & Mays L.W., 1994).

$$F(t) = \frac{dF(t)}{d} \tag{2}$$

The Horton (1933) infiltration equations where Eagleson, P.S. (1970) and Raudkivi. A.J. (1979) showed that the Horton equation can be derived from the Richard equation (1931) or the Philips equation (1957, 1969) that solved the equation of Richards L.A. (1931) under less restrictive conditions developed from approximate solutions of the Richards equation. An alternative has been developed from physical theories with better approximations and with more accurate analytical solutions (Chow V.T., Maidment D.R., & Mays L.W., 1994). Several methods are available to determine the hydraulic conductivity of the soil from the infiltration data (M. Fatehnia, K. Tawfig & T. Abichou, 2014), an example of which we have the Green W.H. & Ampt G.A. (1911) and the one from Zhang (1997a; 1997b; 1988).

To find the soil infiltration rate, the volume of water must be recorded at regular intervals of time as the water infiltrates. For the infiltration of an infiltrometer of tension disc, a formula is needed to take into account the absorption of water laterally. The hydraulic properties of the soil are usually calculated from the infiltration rates in stable state, which are calculated from the fall in the water level in the water supply reservoir. However, there are some methods that use transient infiltration data to calculate the hydraulic conductivity of the soil (Zhang 1998)

**a) Green and Ampt method**

Among the different infiltration equations, the Green and Ampt equation (1997a) based on physics laws shows more accurate solutions. By applying Darcy's law, the infiltration rate in the Green model and Ampt under constant surface head can be described as (Bouwer, H. 1969).

$$\frac{dI}{dt} = K\frac{H+z-\Psi f}{z} \tag{3}$$

Donde:

$\frac{dI}{dt}$ = Tasa de infiltración (cm/min)

t = tiempo (min)

K = conductividad hidráulica detrás del frente humectante (cm/min)

H = Cabeza de agua superficial (cm)

z = distancia vertical desde la superficie del suelo hasta el frente de humedecimiento (cm)

$\Psi f$ = cabeza de succión frontal humectante (cm)

Chow V.T., Maidment D.R., & Mays L.W., (1994), shows average values of the parameters of Green. Ampt for different kinds of soils that analyzed Rawls W., Brakensiek D. & Miller N., (1983) from the method presented by Brakensiek, D., Engleman, R., & Rawls W., (1981) using the equation of Brooks R. & Corey A., (1964). Table 1 shows the infiltration parameters of Green-Ampt for various types of soils.

**Table 1: Infiltration parameters for various soil classes** (Rawls, Brakensiek & Miller. 1983)

| Soil texture class | porosity η | Effective porosity θc | Soil suction head on the wet fron Ψ (cm) | Hydraulic conductivity K (cm/h) |
|---|---|---|---|---|
| Sand | 0.437 | 0.417 | | 11.78 |
| Loamy sand | 0.437 | 0.401 | 6.13 | 2.99 |
| Sandy loam | 0.453 | 0.412 | 11.01 | 1.09 |
| Loam | 0.463 | 0.434 | 8.89 | 0.34 |
| Silt loam | 0.501 | 0.486 | 16.68 | 0.65 |
| Sandy clay loam | 0.398 | 0.330 | 21.85 | 0.15 |
| Clay Loam | 0.464 | 0.309 | 20.88 | 0.10 |
| Silty clay loam | 0.471 | 0.432 | 27.30 | 0.10 |
| Sandy clay | 0.430 | 0.321 | 23.90 | 0.06 |
| Silty clay | 0.479 | 0.423 | 29.22 | 0.05 |
| Clay | 0.475 | 0.385 | 31.63 | 0.03 |

**b) Zhang method**

The initial method proposed by Zhang (1997b) is based on the infiltration model of the disk infiltrometer, according to the following equation:

$$I = C1t^{0.5} + C2t \quad (4)$$

Donde:

I = Infiltración acumulada (L)

t = Tiempo (T)

C1 (L $T^{-\frac{1}{2}}$) y C2 (L $T^{-1}$) = Parámetros.

Zhang (1997a) proposed a simple method that works well to measure the hydraulic conductivity of infiltration data in the dry soil. The method requires measuring the accumulated infiltration as a function of time and adjusting the results with the equation (7), where the parameters C1 ($L\ T^{-\frac{1}{2}}$) and C2 ($L\ T^{-1}$) are in function to the sorptividad of the soil and hydraulic conductivity respectively. The hydraulic conductivity of the soil (K) is calculated from:

$$K = \frac{C1}{A} \quad (5)$$

Where C1 can be found by adjusting a second order polynomial to the data for the accumulated infiltration versus the square root of time, and A is a value that relates the parameters of Van Genuchten for a type of soil given with the suction rate and the radius of the disk infiltrometer. A is calculated from:

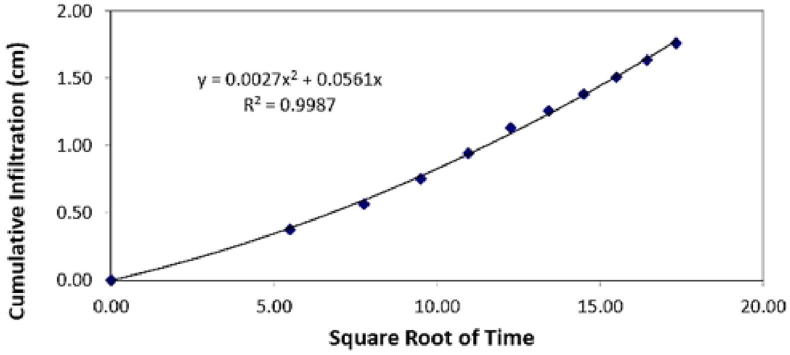
$$A = \frac{11.65\ (n^{0.1}-1)\exp[2.92(n-1.9)\alpha h}{(\alpha r)^{0.91}}, \quad n > 1.9 \quad (6)$$

$$A = \frac{11.65\ (n^{0.1}-1)\exp[7.5(n-1.9)\alpha h}{(\alpha r)^{0.91}}, \quad n < 1.9 \quad (7)$$

Where ***n*** and ***α*** are the parameters of Van Genuchten for the soil, ***r*** is the radius of the disc and ***h*** is the suction on the surface of the disc. The parameters of van Genuchten for different texture classes can be obtained from Carsel, R.F. & Parrish, R.S. (1988).

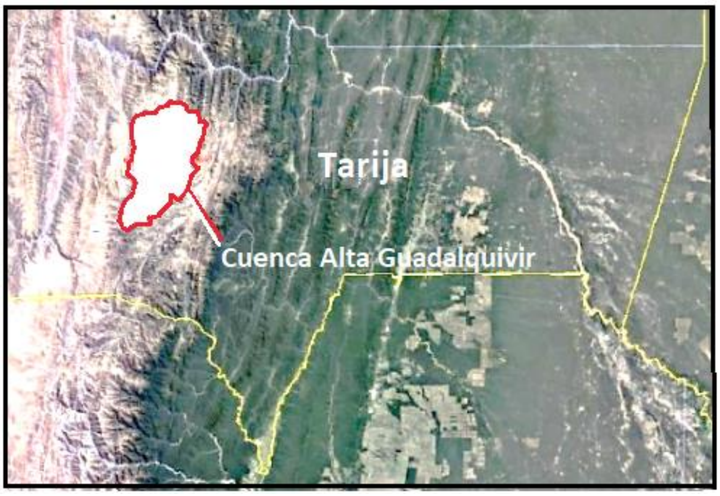
In the Excel spreadsheet that provides the procedure for the Decagon Devices, Inc., (2016) includes a quadratic equation used to calculate C1, which is the slope of the line denoted as "y", Figure 1 gives an example (P. Sihag, P., Tiwari, N.H. & Ranjan, S. 2017).

**Figure 1. Figure of the quadratic equation - cumulative infiltration vs. Root block of a soil's time**




The Guadalquivir Basin is in Tarija, Bolivia, circumscribes the urban area of the municipality of Cercado and represents the largest population of the department (Copa and Villena, 2016). The Guadalquivir River is one of the most important sources of irrigation and drinking water in the population (Programa Estratégico de Acción-PEA, 1999). Figure 2 shows the location of the Guadalquivir Basin in the department of Tarija.

**Figure 2. High basin of the Guadalquivir in the Department of Tarija**




The hydrological information necessary for the planning of water resources in the Guadalquivir basin regarding the characteristics and properties of soils, vegetation cover, hydraulic properties such as infiltration and hydraulic conductivity is very scarce (Villena E. et al., 2018).

## 2. Objective

This work aims to show the hydraulic properties of soils such as infiltration and hydraulic conductivity and characterization maps of the soils of the sub-basins of Rincón de la Vittoria and the Quebrada del Monte of the Guadalquivir Basin, after an experimental process carried out in the areas of study using for the effect infiltrometers mini disk.

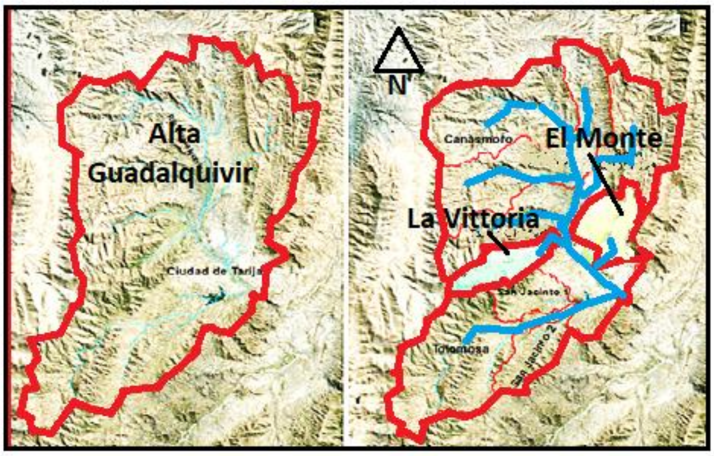
## 3. Materials and methods

The methodology used for the experimental process of the project in the study sub-basins is described.

### 3.1. Area of study

The high Guadalquivir Basin is in the Department of Tarija, Bolivia, with an approximate extension of 1540 km² (Copa Y & Villena, 2016). It is formed by 8 sub-basins corresponding to the main tributaries of the Guadalquivir River (Ministerio de Medio Ambiente y Agua, 2016), Figure 3, shows the working areas of the present study.

**Figure 3. The Guadalquivir basin and the sub-basins of Rincón de la Vittoria and Quebrada del Monte**




The sub-basin of Rincón de la Vittoria has an approximate extension of 6,115 ha. is located inside the reserve of Sama (Servicio Nacional de Áreas Protegidas -SERNAP, 2018) which is also the area where the largest and most important volume of water is extracted for the Cooperativa de Servicios de Agua Potable y Alcantarillado Saneamiento de Tarija, Cosaltt LTDA (2015). The sub-basin of the Quebrada del Monte has an extension of approximately 4,383 ha. and represents one of the most important expansion areas of the Central Valley of the city of Tarija.

### 3.2. Infiltrometer mini disk

For the field trials were used 3 mini disk infiltrometers (Decagon Devices, Inc., 2016), Ankeny M.D. et al. (1991) notes that this simple method of measurement in the field of hydraulic conductivity is more valuable because of its rapidity than the methods of hydraulic gradient used in laboratory and less damaging to the continuity of pores than other techniques of field infiltration.

Infiltrometer mini disk is ideal for field work for its compact size and for the little water it requires for its operation, allowing easy transport in addition to be a properly functioning equipment in unsaturated soils (Decagon Devices, Inc., 2016),

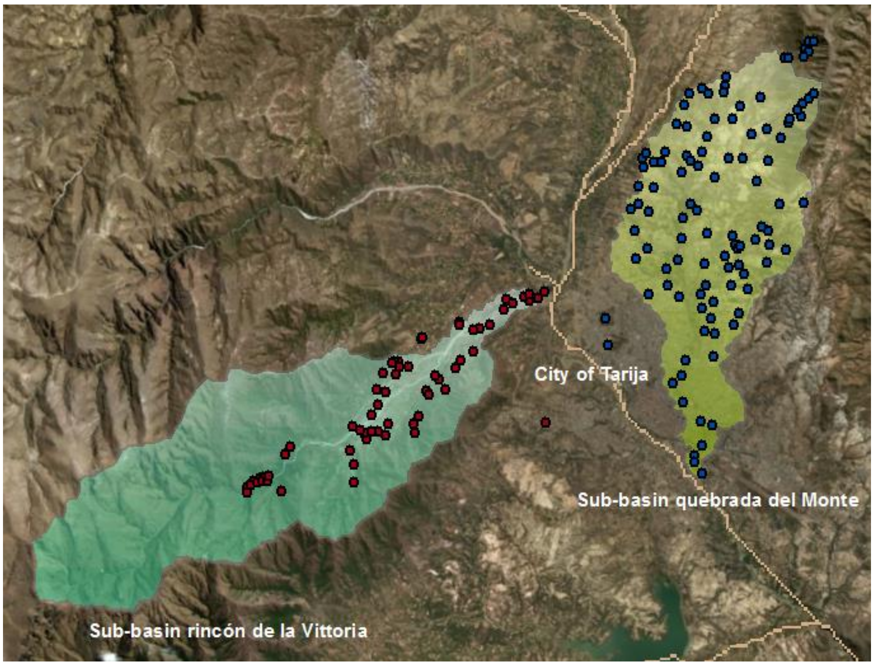
Following the procedure recommended by Decagon Devices, Inc., (2016), and detailed by S. Matula, S. et al., (2015), A good and consistent hydraulic contact between the membrane of the measuring device and the soil is essential for the infiltrometer, as the part bottom of the infiltrometer has a porous sintered stainless-steel disc does not allow the water to escape outdoors. The small diameter of the disc allows undisturbed measurements on relatively level soil surfaces.

Due to the type of soils that predominate in the study areas and the characteristics of the infiltrometer of Minidisc tension, the hydraulic conductivity has been calculated using the method of Zhang (1997a), for its simplicity and for an adequate operation in soils dry – unsaturated.

### 3.3. Sampling points

For the sub watershed of Rincón de la Vittoria, 62 points were explored in accessible areas, this sub-basin is characterized by a very steep topography and inaccessible areas, in the sub-basin of the Quebrada del Monte were explored 111 Points distributed throughout the sub-basin (Cárdenas, M. et al. 2018). Figure 4 shows the distribution of the analysis points in the study areas.

**Figure 4. Sampling points – Rincón de la Vittoria y la quebrada del Monte**




### 3.4. Test methods

For the implementation of the mini disk equipment we proceeded to level the contact surface between the disk and the ground to avoid disturbances during the measurements, once the infiltrometer was placed in the ground, the water starts to leave the lower chamber and It infiltrates at a certain speed according to the hydraulic properties of the soil. As the water level drops, the volume is recorded at specific time intervals. Subsequently, the data were plotted using an EXCEL spreadsheet that provides Decagon Devices, Inc. (2016), this data allowed calculating the hydraulic conductivity.

#### 3.4.1. Preparation and calibration

The calibration process of the equipment has consisted in:

1. Fill the bubble chamber three-quarters completely by running the water through the suction control tube or removing the top cap. Once filled, the suction control tube is fully downward inverted the infiltrometer will remove the lower elastomer with the porous disc and fill the water tank.
2. The position of the end of the Mariotte tube with respect to the porous disc is carefully adjusted to ensure a suction zeroing while the tube bubbles. If this dimension is accidentally changed, the end of the Mariotte tube must be reset to 6 mm from the end of the plastic tube of the water tank.
3. Replace the lower elastomer, ensuring that the porous disc is firmly in place, the infiltrometer must be kept upright to prevent leakage.
4. To start the field readings, the disc was made to make a complete contact with the surface of the ground, ensuring a uniform dispersion of the water.

#### 3.4.2. Suction rates

The suction rate has changed according to the different soils found during the sampling a suction rate of 2 cm was used for soils of medium particle size (mixed), in the sandy soils it was adjusted to 6 cm and for the more compact soils like the clayey one's A suction rate of 0.5 cm was used.

### 3.4.3. Calculation method

The method of Zhang (1997a) has been used for calculating the hydraulic conductivity in the present study, this being the most advisable for unsaturated soils following also the methodology proposed by Decagon Devices INC. (2016) for the processing of Data.

The classification of soils, the infiltration parameters of Green-Ampt were used for different types of soils detailed in table 1.

### 3.4.4. Reading and analyzing field data

M. Fatehnia, K. Tawfig & T. Abichou, (2014) point out that infiltration rates at the end of each test were considered the rate of stable infiltration and were used to find hydraulic conductivity values using the Zhang method, (1998) that Requires initial and final water content along with infiltration rates for the various successive suction values.

When the equipment was placed on the ground, the infiltration measurements corresponding to the readings calculated as the difference in the volumes of water observed at different measuring times were carried out, figure 5 illustrates different moments of measurements Carried out in different sampling places.

**Figure 5. Field measurements**


## 4. Results

Figure 6 shows the soil characterization maps based on the hydraulic conductivity of the subwatersheds of Rincón de la Vittoria and the Quebrada del Monte, calculated from the infiltration data obtained with the field for the different types of Soils, 63 points explored in La Vittoria and 111 in the Del Monte.

Figure 7 shows the infiltration curves for the different types of soils in the sub-basins of studies.

Table 2, details the areas by type of soils of the sub watersheds studied and the tables 3 and 4 detail the hydraulic conductivity "K" calculated for each sample point of the study sub-basins.

**Figure 6. Map of characterization and hydraulic conductivity of soils, Sub-basin Rincon de la Vittoria and Quebrada del Monte**

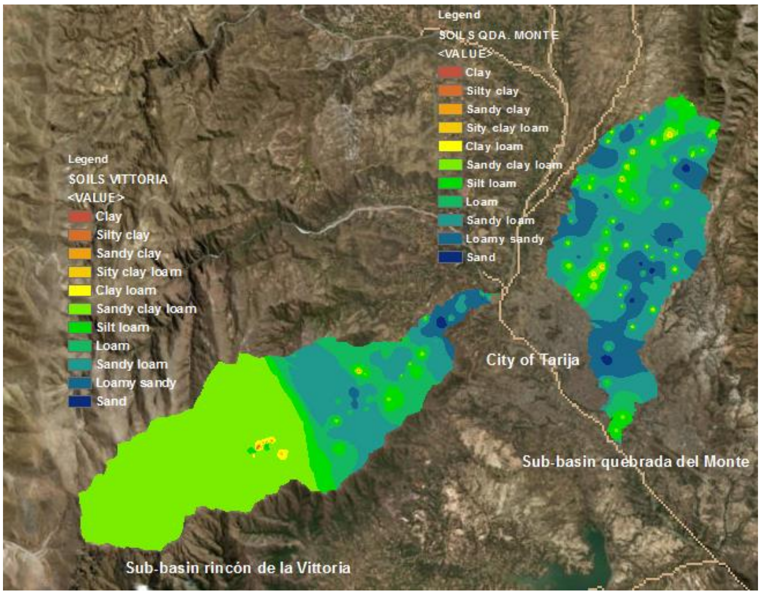



**Figure 7: Infiltration curves**

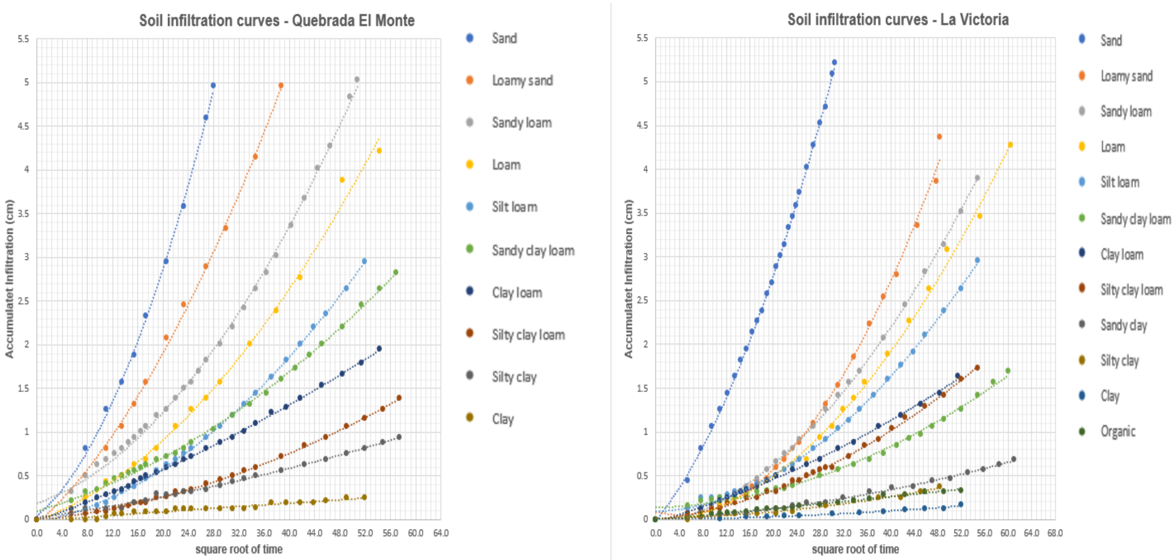



**Table 2: Areas according to type of soil - gulch of the corner of the Vittoria and the Quebrada del Monte.**

| Soil texture class | Rincón de la Vittoria | | Quebrada del Monte | |
|---|---|---|---|---|
| | Has. | (%) | Has. | (%) |
| Sand | 0.62 | 0.01 | 0.16 | 0.004 |
| Loamy sand | 1.55 | 0.03 | 0.73 | 0.017 |
| Sandy loam | 1.34 | 0.02 | 0.36 | 0.008 |
| Loam | 6.84 | 0.11 | 5.81 | 0.133 |
| Silt loam | 27.7 | 0.45 | 11.63 | 0.265 |
| Sandy clay loam | 3556.26 | 58.13 | 100.97 | 2.304 |
| Clay Loam | 365.45 | 5.97 | 464.72 | 10.603 |
| Silty clay loam | 811.91 | 13.27 | 740.05 | 16.885 |
| Sandy clay | 1128.95 | 18.45 | 2018.24 | 46.049 |
| Silty clay | 204.06 | 3.34 | 1011.88 | 23.088 |
| Clay | 13.14 | 0.21 | 28.24 | 0.644 |
| **TOTAL** | **6117.82** | | **4,382.79** | |

**Table 3: Hydraulic conductivity - Quebrada del Monte**

| Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 3.13 | **24** | 0.22 | **47** | 16.28 | **70** | 13.29 | **93** | 0.32 |
| **2** | 0.16 | **25** | 0.10 | **48** | 0.07 | **71** | 0.40 | **94** | 0.26 |
| **3** | 0.25 | **26** | 0.12 | **49** | 0.05 | **72** | 16.74 | **95** | 0.71 |
| **4** | 0.42 | **27** | 0.12 | **50** | 0.25 | **73** | 0.03 | **96** | 1.37 |
| **5** | 0.19 | **28** | 1.57 | **51** | 3.16 | **74** | 4.40 | **97** | 0.03 |
| **6** | 3.77 | **29** | 0.86 | **52** | 0.16 | **75** | 0.10 | **98** | 0.21 |
| **7** | 0.24 | **30** | 0.31 | **53** | 0.12 | **76** | 0.27 | **99** | 0.19 |
| **8** | 0.14 | **31** | 0.01 | **54** | 0.08 | **77** | 0.10 | **100** | 4.37 |
| **9** | 0.07 | **32** | 3.90 | **55** | 9.38 | **78** | 4.02 | **101** | 0.06 |
| **10** | 0.04 | **33** | 8.53 | **56** | 19.00 | **79** | 0.22 | **102** | 1.24 |
| **11** | 2.98 | **34** | 14.64 | **57** | 0.33 | **80** | 0.10 | **103** | 1.42 |
| **12** | 0.09 | **35** | 3.99 | **58** | 0.37 | **81** | 0.25 | **104** | 1.68 |
| **13** | 0.33 | **36** | 0.47 | **59** | 4.55 | **82** | 0.27 | **105** | 0.32 |
| **14** | 0.23 | **37** | 0.18 | **60** | 3.39 | **83** | 13.84 | **106** | 0.71 |
| **15** | 11.48 | **38** | 1.40 | **61** | 0.50 | **84** | 0.32 | **107** | 0.65 |
| **16** | 0.05 | **39** | 0.13 | **62** | 2.88 | **85** | 0.40 | **108** | 0.29 |
| **17** | 1.65 | **40** | 0.28 | **63** | 0.81 | **86** | 0.03 | **109** | 0.39 |
| **18** | 3.14 | **41** | 0.02 | **64** | 0.62 | **87** | 0.33 | **110** | 0.29 |
| **19** | 0.23 | **42** | 0.10 | **65** | 10.15 | **88** | 10.13 | **111** | 0.73 |
| **20** | 10.66 | **43** | 0.25 | **66** | 4.76 | **89** | 0.32 | | |
| **21** | 0.20 | **44** | 0.24 | **67** | 0.11 | **90** | 1.85 | | |
| **22** | 1.04 | **45** | 0.11 | **68** | 4.91 | **91** | 0.07 | | |
| **23** | 0.36 | **46** | 0.70 | **69** | 0.23 | **92** | 5.12 | | |

**Table 4: Hydraulic conductivity – Rincón de la Vittoria**

| Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) | Point | K (cm/h) |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 21.91 | **14** | 0.36 | **27** | 0.03 | **40** | 0.30 | **53** | 0.28 |
| **2** | 11.76 | **15** | 12.98 | **28** | 0.06 | **41** | 0.03 | **54** | 0.18 |
| **3** | 3.03 | **16** | 0.25 | **29** | 0.04 | **42** | 0.09 | **55** | 0.11 |
| **4** | 0.35 | **17** | 0.30 | **30** | 5.20 | **43** | 0.41 | **56** | 0.34 |
| **5** | 0.12 | **18** | 2.20 | **31** | 0.80 | **44** | 0.26 | **57** | 1.59 |
| **6** | 2.91 | **19** | 0.62 | **32** | 0.35 | **45** | 0.49 | **58** | 0.22 |
| **7** | 0.79 | **20** | 0.31 | **33** | 0.24 | **46** | 1.16 | **59** | 0.60 |
| **8** | 0.01 | **21** | 0.66 | **34** | 0.22 | **47** | 2.26 | **60** | 2.70 |
| **9** | 0.01 | **22** | 4.94 | **35** | 0.41 | **48** | 1.52 | **61** | 0.64 |
| **10** | 0.01 | **23** | 0.18 | **36** | 0.78 | **49** | 3.65 | **62** | 0.17 |
| **11** | 0.01 | **24** | 0.26 | **37** | 0.88 | **50** | 0.11 | **63** | 0.96 |
| **12** | 0.18 | **25** | 1.35 | **38** | 2.71 | **51** | 4.90 | | |
| **13** | 0.33 | **26** | 0.67 | **39** | 1.05 | **52** | 0.49 | | |

## 5. Conclusions

The study shows the different trends of soils in the sub-basins of the Guadalquivir, whereas in the corner of the Vittoria the soils predominate loam sand clayey with greater presence of vegetations, in the sub-basin of the Quebrada del Monte, one observes less vegetation with a higher trend of soils such as sandy loam and loamy sand.

The infiltration curves and the prevailing soil types in the Rincón de la Vittoria sub-basin include low infiltrations in long times, while in the mountain gorge, medium and high infiltrations are observed in shorter times.

There is a lot of variability in the hydraulic conductivity of the different soils studied, according to the classification of Brooks & Corey (1964) for the Rincón de la Vittoria basin only 0.21% of the soils are of clayey tendency by the conductivity hydraulics varying from 11.76 to 21.91 (CM/h), 0.62% are soils that vary between sand and silt loam the hydraulic conductivity of these soils are between 0.01 and 0.15 (cm/h), the biggest trend in the sub-basin corresponds to sandy clay loam soils to silty clay with more than 99% whose hydraulic conductivity varies from 0.15 to 5.20 (cm/h).

In the sub watershed of the Quebrada del Monte is observed a similar behavior, 0.64% corresponds to clay with a hydraulic conductivity varying from 10.13 to 19 (CM/h) Over 98% corresponds to soils sandy clay loam and silty clay with conductivity that vary Between 0.16 and 9.38 (CM/h), only 0.43% correspond to sand and silty loam soils where the hydraulic conductivity parameters vary between 0.01 and 0.14 (CM/h).

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