12 Impact of Land Use Changes in the Surface Hydrodynamics of a Water-harvesting Basin

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12.1 Introduction[1, 2]

Watershed management requires systematic measurements in order to reach good resources control. Some processes conditioning water transfers in the environment such as rain, run-off, infiltration, deep percolation, water uptake by plants, and evapotranspiration should be quantified to improve our knowledge of hydrological characterization and of the best management practices (Descroix/Nouvelot, 1997; Descroix et al., 2004). This work presents infiltration measurements and results produced with the Suction Disc Infiltrometer method realized in the Upper Nazas River Basin. This basin is the main water supply for Irrigation District 017 in northern Mexico, called the Lagunera region. Results show that soil surface controls the hydrodynamic behaviour of the watershed. Land use changes can be linked with productive practices that are causing strong hydrological consequences.

Watershed management is a priority issue in many regions of the world especially in arid and semi-arid lands where water is the main limiting factor for production and economic development (Sanchez, 2005; Loyer, 1998). Since the late 20th century, the organization of watershed councils for major rivers in Mexico has pursued the integrated management of water basins as part of the effort to solve the complex set of water problems: supply, quality, sanitation and cost, raised from several production sectors and user types: agriculture, livestock, industrial and urban public (Gonzalez Barrios et al., 2007).

Water is a key resource and driver of economic development for many regions in Mexico; and it is an element whose presence depends on the conditions of the natural environment, but also on the influence of productive activity. Therefore, managing water basins requires a good knowledge of the natural and productive systems that use water or have a decisive influence on water quality. Watershed parameterization is therefore a matter of prime importance as a source of information.

After a brief introduction to the study area, this chapter will present the materials and methods used as well as the results and their implications for the upper Nazas River basin and for its dependent cropping area.

12.2 Study Area

The research was conducted in a catchment located in the Upper Nazas River Basin (figure 12.1). The 'Cienega de la Vaca' watershed is located in the mountain range of the Sierra de la Candela that conforms to the Sierra Madre Occidental in the northern state of Durango (SEMARNAT, 2007) and includes parts of the municipalities of Guanacevi, Santa Maria del Oro and Tepehuanes (figure 12.2). The Sierra de la Candela has an approximate area of 1200 km^2 and its altitude ranges from 2,500 to 3,200 metres above sea level. Its shape is quite elongated from north to south with a landform characterized by hilly slopes. The main geological components are rhyolite-ignimbrite, as in most of the western Sierra Madre (Descroix et al., 2001).

The hydrological network of the Sierra de la Candela is formed by two main tributaries of the Sixtin-El Oro River flowing northward and then south-eastward; and the Tepehuanes (flowing north to south) – Santiago (south to north, in the same *graben*), called

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2 Key words: watershed management, infiltration, hydrological cycle.

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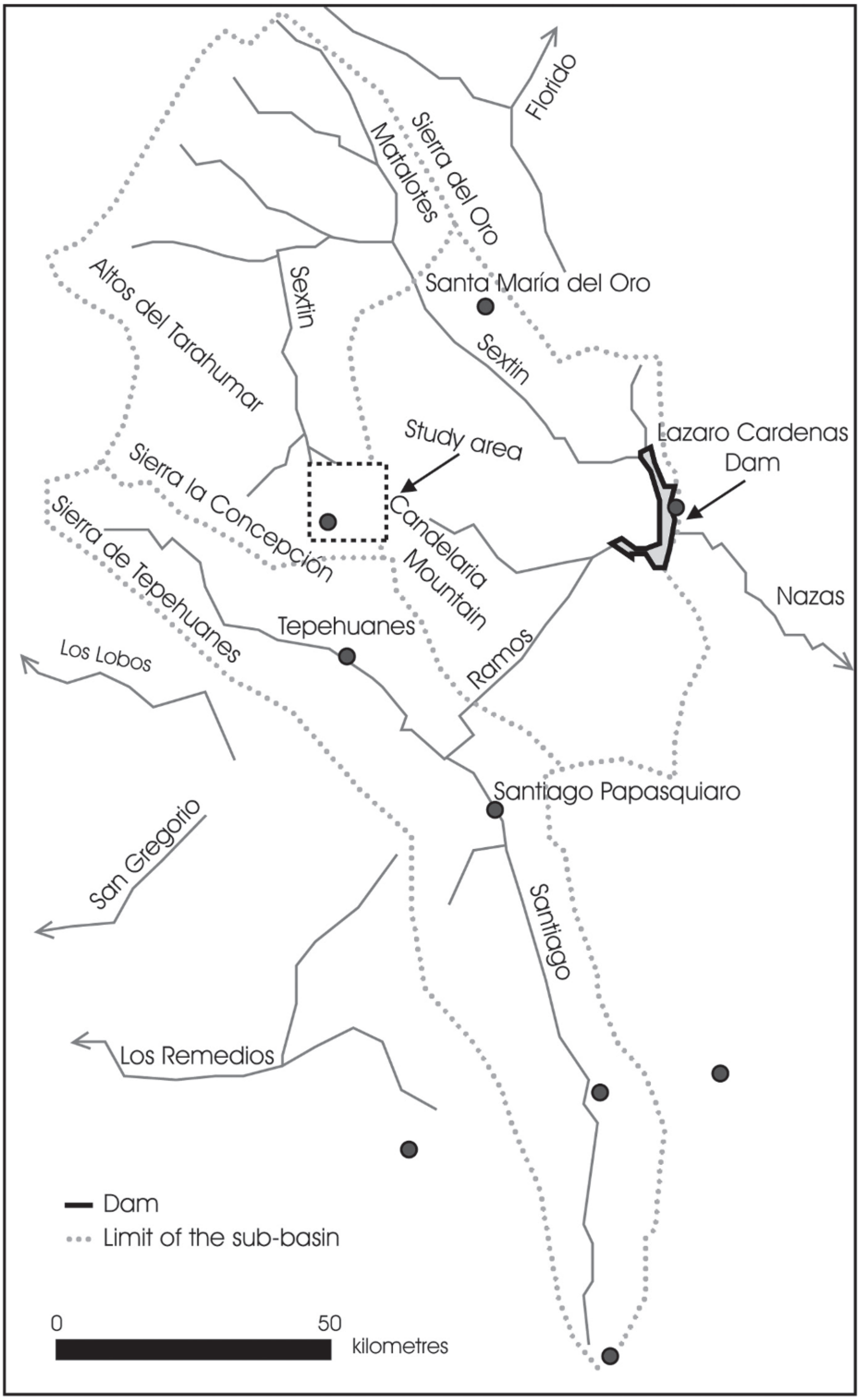
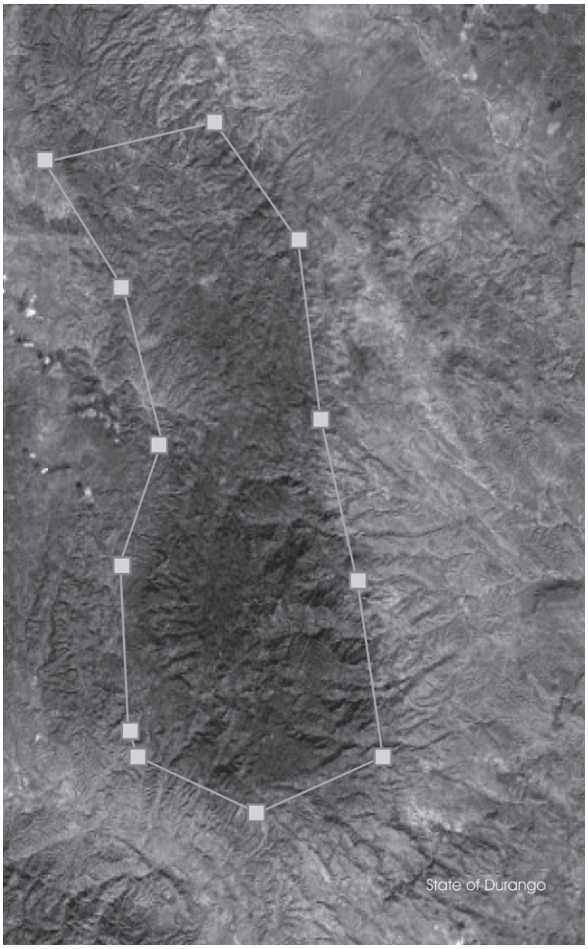
Figure 12.1: Location of the Upper Nazas River Basin. **Source:** Authors' research data.



Ramos River after their junction. Both (the Ramos and Sixtin rivers) meet at the Lazaro Cardenas reservoir (Descroix, 1995). The predominant run-off process is of the Hortonian type (Horton et al., 1933; Descroix et al., 2002) but under certain conditions of soil capacity for water storage a subsurface run-off or Hewlettian-Cappusian type was observed, consisting of contributory water-saturated zones (Cappus, 1960, Hewlett et al., 1969).

Figure 12.2: Sierra de la Candela. **Source:** Image from Google Earth in the public domain.



In the Sierra de la Candela, some important forest resources remain, especially pine and oak forests that have been used since the mid-20th century in different patterns and locations, but generally over-exploited (Rodriguez, 1997; Descroix et al., 1998). Wood is carried to the main sawmills of Parral, Chihuahua, Santiago Papasquiaro and Durango (Viramontes et al., 2004). This forest plays a crucial role for the hydrological and environmental services offered by the Sierra de la Candela in terms of water capture and transfer, since it receives an annual average of 840 million cubic meters of rainwater, given an average rainfall of 700 mm over its total area.

The 'Cienega de la Vaca' watershed occupies 18 km^2 approximately in the highest part of the Sierra de la Candela (2,700 to 3,180 meters above sea level). This watershed belongs to the 'Ejido Peña y su anexo El Salto' in the municipality of Santa Maria del Oro Durango, whose productive activities are forestry and livestock. The predominant vegetation in the watershed is pine and oak forest on Cambisol type soils (FAO, 1998), many of which have mulch consisting of both deciduous species (oak) and conifers (pines). In the valleys of the basin there are grazing areas on slightly deeper soils (Gonzalez Barrios et al., 2000).

12.3 Methods

Four sites were chosen as representative of the main surface features present on the watershed. Infiltration test were made on each one of them. These selected surfaces are pine mulch, oak mulch, grass and bare soil (degraded by cattle trampling). The Suction Disc Infiltrometer method proposed by Vandervaere (1995) and Perroux & White (1988) was employed to measure the infiltration capacity at a constant controlled load (figure 12.3) with three different radio discs (4, 10 and 12.5 cm) and four pressure head values planted in the soil (-100, -60, -30 and -10mm). For each measurement point other complementary parameters were determined with classical laboratory methods (Plenecassagne et al., 1997). These parameters are soil texture, bulk density, water content and initial soil moisture at field capacity. All these data allow the characterization and quantification of soil hydraulic conductivity depending on the surface features (figures 12.4 to 12.8).

At least three tests were carried out on each type of soil surface, applying different suction values from -100 mm to -10 mm (table 12.1).

Table 12.1: Number of infiltration tests conducted in each type of surface. **Source:** Authors' research data.

Soil surface:	N total	N (disc of 12.5 cm)	N (disc of 10 cm)	N (disc of 4 cm)
Pine mulch	19	7	6	6
Oak mulch	3	0	2	1
Grass	26	8	11	7
Trampled bare soil	7	0	0	7

12.4 Results

The infiltration tests conducted in the main types of soil surfaces of the watershed reveal large spatial variability of hydraulic conductivity in the soils. Sensitive

Figure 12.3: Suction Disc Infiltrometer. **Source:** Vandervaere (1995).

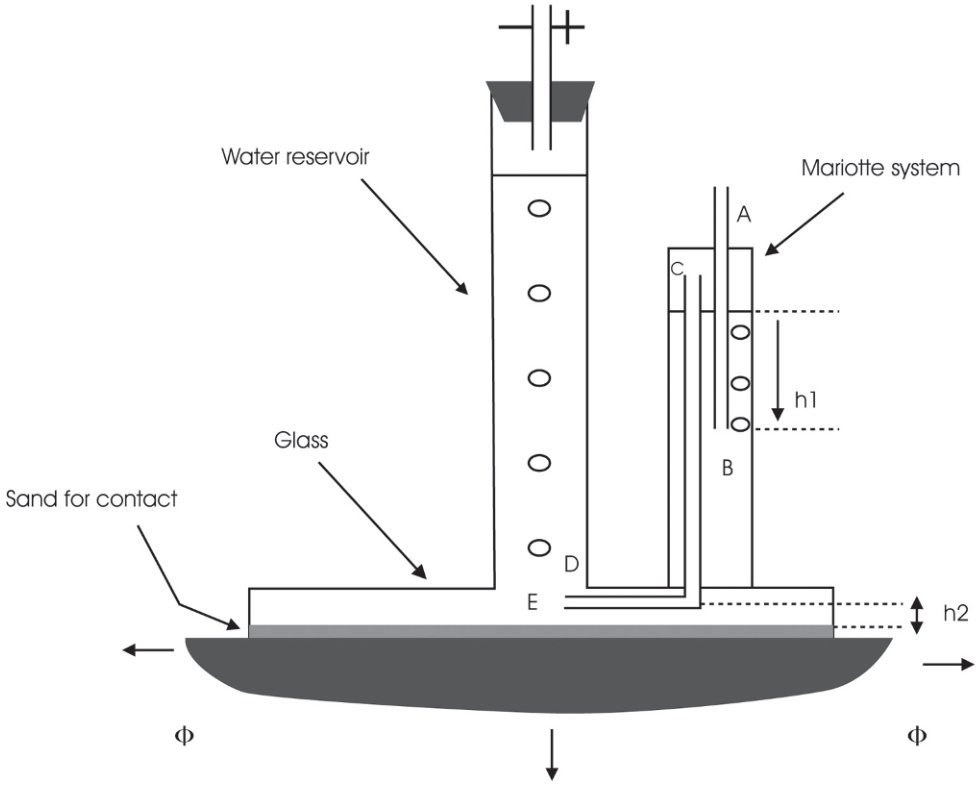


Figure 12.4: Surface of pine mulch. **Source:** Photo from research taken by members of the team.

differences are observed between the unstructured porous medium on bare soils degraded by cattle trampling and the well-structured porous medium on pine or oak mulch surfaces. The grassland areas have an intermediate behaviour.

Figure 12.5: Surface of oak mulch. **Source:** Photo from research taken by members of the team.

Figure 12.6: Surface of grass. **Source:** Photo from research taken by members of the team.

Figures 12.8, 12.9 and 12.10 show the results of infiltration tests on three different surfaces. In all figures the water flow is greatly reduced during the first few seconds, then it fluctuates a moment in order to stabilize. This stabilization can be interpreted as a steady state having been reached. Then the suction applied by the

Figure 12.7: Surface of bare soil degraded by cattle trampling. **Source:** Photo from research taken by members of the team.

Mariotte system is changed to a lower value, and the flow increases and becomes stable after a certain time. The operation is repeated for different suctions at -100, -60, -30 and -10 mm. Although in most cases the flow increases with decreasing suction applied, there are exceptions, particularly for tests carried out with the large disc (12.5 cm) in the pine mulch surface (figure 12.9).

The infiltration flux is not stabilized at a suction of -100 mm and does not increase when the value of suction is changed, but sometimes the flow increases a long time after the suction. After observing this relationship, the suction rate was deliberately increased to show whether the flow decreased to the previous value observed. It was found that the values of flow at the suction of -30 mm are quite similar to those observed during the initial test phase, although the applied suction of -60 mm and -100mm is smaller (hysteresis phenomenon).

When applying a -10 mm suction in this test (figure 12.10) the phenomenon of soil surface wetting can be described as follows: at the beginning of the test the soil surface is dry: the system behaves as hydrophobic; it becomes hydraulic-conductive after more than 4 hours, while the angle of the surface water meniscus in contact with the solid surfaces becomes smaller, allowing more water to infiltrate. Subsequent flow analyses with decreasing suction and later increasing suction shows that this effect is irreversible and that it may be linked to the organic nature of the mulch components.

In physical terms, the hydraulic conductivity K is not constant when the medium is not saturated, but varies with water content θ (or pressure head h). When moisture decreases, a decrease in hydraulic conductivity is observed. The relationship between the hydraulic conductivity and the pressure head K (h) depends very strongly on soil texture. Under saturation conditions ($h \geq 0$), K takes the highest value, called saturation hydraulic conductivity Ks.

Because ($h < 0$) in unsaturated conditions, and K varies depending on h, we can use the following exponential relationship to describe this change (Gardner, 1958):

$$K(h) = Ks \exp(\alpha h) \quad (1)$$

where α is a parameter characteristic of soil texture.

Using the method of Ankeny et al. (1991) and Reynolds/Eldrick (1991), the soil hydraulic conductivity can be obtained depending on the suction applied, and the saturation hydraulic conductivity (Ks) deduced as well as the average value of α using the pressure head intervals applied (from -100 mm to -10 mm) fitting the experimental data (presented in figures 12.8, 12.9 and 12.10) to the exponential relationship between hydraulic conductivity and suction of equation (1). The results of this calculation are presented in table 12.2.

Table 12.2: Values of Ks and α calculated for three soil surfaces. **Source:** Research data-

Surface type:	Ks (mm/h)	α (mm^{-1})	α_{sat} (mm^{-1})
Pine mulch	60.84	0.070	0.017
Grass	46.44	0.021	0.047
Bare soil degraded by trampling	54.72	0.048	0.050

The calculation with equation (1) implies that α is constant in the range 0 to -100 mm, but in reality this parameter is linked to a hydraulically functional pore size and can vary depending on the applied suction. It follows that the α_{sat} value corresponds to α value with a suction of 0 mm which is obtained by extrapolation according to the following empirical relationship,

$$\alpha(h) = \alpha_{sat}\exp(\beta h) \quad (2)$$

where β is a fitting parameter.

According to capillary theory (White/Sully, 1987) we can get an idea of the size of hydraulically functional pore size with the next equation,

$$\lambda_m = \frac{\sigma\alpha}{\rho_w g} \quad (3)$$

where σ is the surface tension (0.073 Newton/meter in standard conditions).

The pore size calculation using equation 3 gives the results presented in table 12.3.

Table 12.3: Functional pore size λm calculated from equation 3. **Source:** Research data.

Surface type	Average pore size (μm) unsaturated conditions. Suction from -100 to -10mm	Pore size (μm) saturated conditions. Suction = 0mm
Pine mulch	521	1281
Grass	156	349
Bare soil degraded by trampling	358	372

The difference between the two pore sizes reflects how soil porosity is structured. In a well-structured soil, the size of functional hydraulic pore varies depending on suction and water-saturated conditions. According to table 12.3 the functional pore size is similar under both conditions for the bare surface. This surface as studied lacks an organized structure for its functional porosity (inter-connectivity between pores of different size), which would be expected in a surface disturbed by cattle trampling. The grass surface is less homogeneous than the bare one, and shows a difference in functional pore size between the two conditions (figure 12.10). This site has better structure and connectivity within the pore network. The surface with pine mulch shows a very structured porous system with a large difference in functional pore size range but with a hydrophobic behaviour that may create a delay in infiltration efficiency.

In each one of the studied surfaces, hydrodynamics will be different and cause different hydrologic impacts downstream. The consequences of uncontrolled production systems such as ranching and forest harvesting can have consequences at the basin scale in terms of infiltration run-off and erosion according to that observed in other parts of the Nazas River Basin by Poulenard (1995; 1996), Gomez (1997), Perez (1998) Descroix et al, (2000), and in terms of quantity and quality of water harvested by the watershed.

These results highlight the importance of soil surface features and measurement of infiltration properties in the service of decision-makers in the management of water transfer basins. It is therefore necessary to measure these parameters in areas where there is no information in order to provide relevant and reliable management recommendations.

12.5 Conclusions

The soil surface features are very important in the processes explaining the hydrodynamics of the basin; they often reflect the way the soil and vegetation are managed in the watershed. The consequences of uncontrolled production systems such as ranching and forest harvesting can be significant at the basin scale in terms of infiltration, run-off and erosion as well as in terms of quantity and quality of harvested water.

Watershed management for water production requires a good knowledge of reliable and robust parameters in order to propose a convenient management of water resources. Given the lack of information, the experimental studies of hydrology and soil science

Figure 12.8: Infiltration tests on bare surface degraded by cattle trampling. **Source:** Authors' research data.

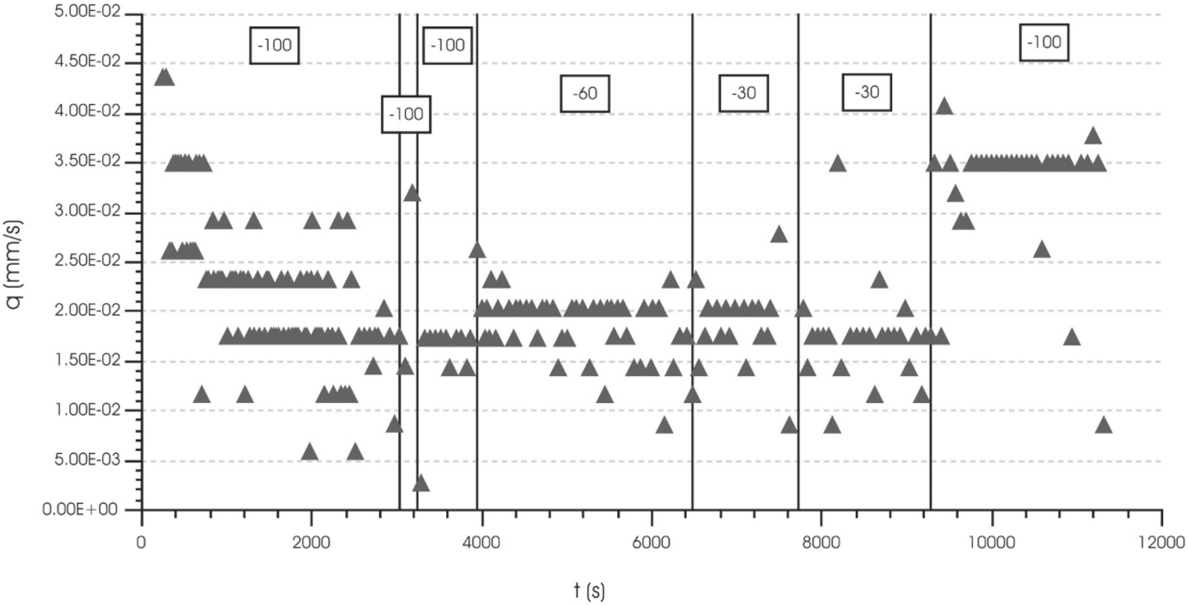
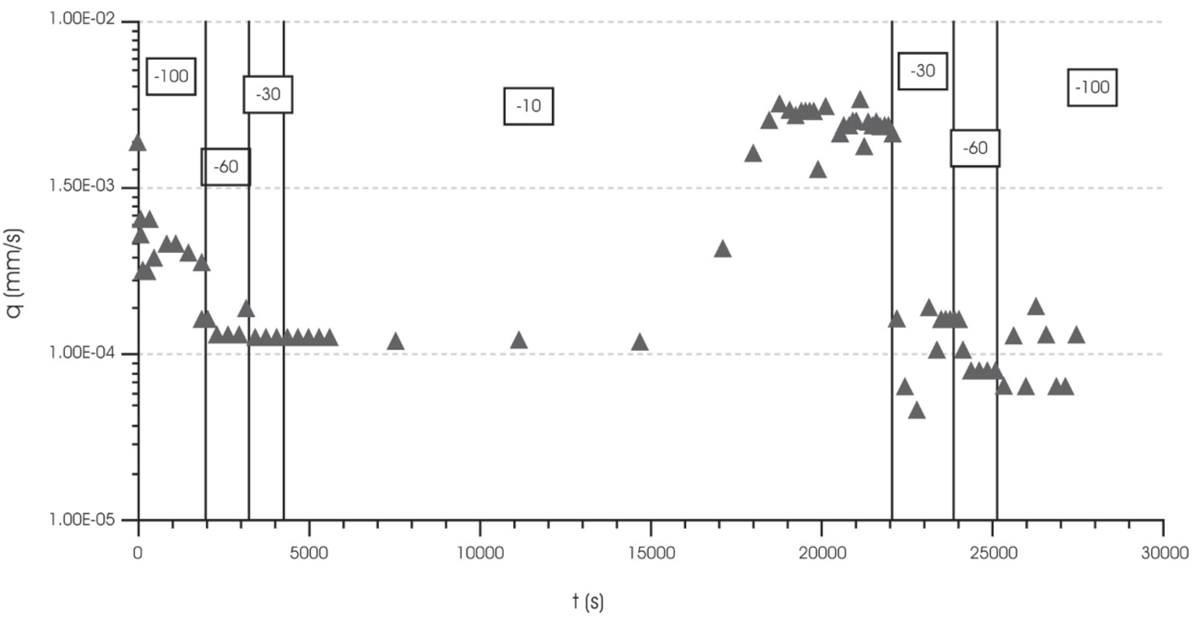


Figure 12.9: Infiltration tests on surface with pine mulch. **Source:** Authors' research data.

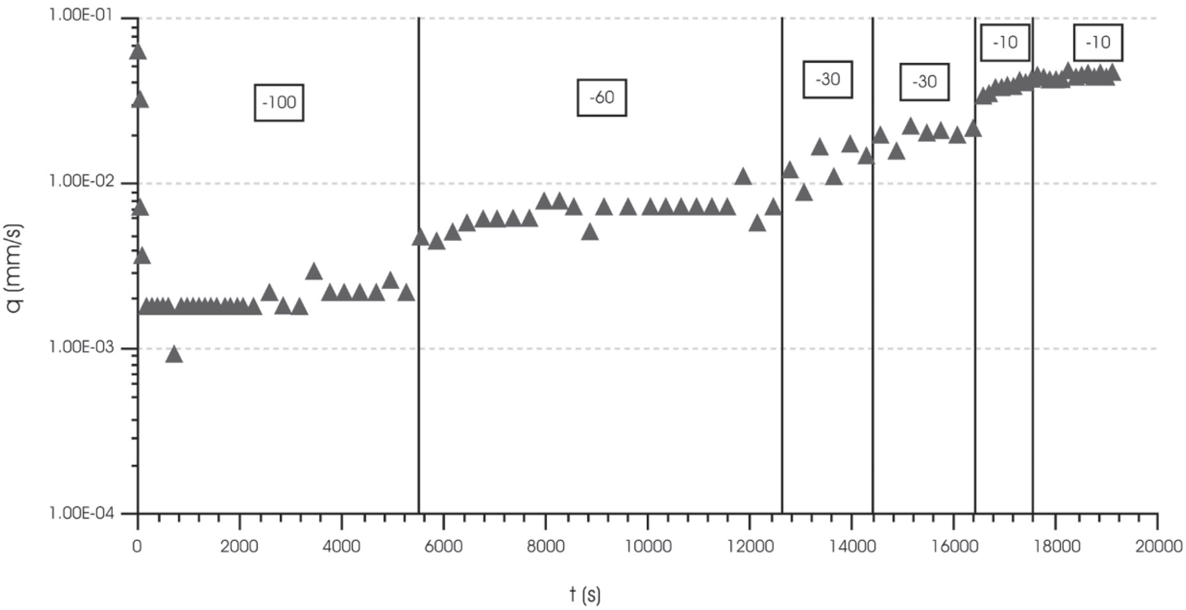


are useful in order to improve understanding and to reliably quantify the hydrological functioning of water-harvesting basins such as that presented in this paper.

The Upper Nazas River Basin is the main source of water supply for agriculture in Irrigation District 017 in Northern Mexico, which has suffered decades of land use changes linked to strong pressure from forestry production, agriculture and livestock. Limited infiltration, accelerated run-off and heavy erosion are some of the hydrological impacts which modify the quantity and the quality of the stream flow of the basin.

The results of this work on experimental infiltration illustrate the importance of limiting production activities in accordance with potential hydrological impacts of the observed features in order to improve soil and water management and to perpetuate water harvesting for the areas that depend on the water supply of the Upper Nazas River Basin.

Figure 12.10: Infiltration tests on grass surface. **Source:** Authors' research data.



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