13 Evapotranspiration in the Upper and Middle Nazas River Basins

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13.1 Introduction

Evapotranspiration, a combination of two simultaneous physical processes which account for the loss of water in vegetation-covered soils, through water evaporation from the moist soil-vegetation surface and control of transpiration through specialized plant tissues (stomata), is a fundamental hydrological variable at regional and basin levels for decision-making aimed at improving the water planning and management demanded by farming activities so as to maximize its usefulness, especially in arid and semi-arid zones where water resources are scarce or uncertain (Pereira et al., 2006; Dinpashoh, 2006; Jacobs et al., 2008). Also, evapotranspiration is an important time and space describer for climate regime classification, especially when related to precipitation. This variable is also a major soil-water balance component (Arora, 2002; Mundo/Martínez, 2002).

The need to know evapotranspiration for various applications has encouraged the development of methods and instruments for measuring and estimating evapotranspiration at a relatively short timescale: millimetres per day (mm d^{-1}), and even shorter intervals (mm h^{-1}). Direct measurement of actual evapotranspiration is usually determined through weighing lysimeters and the gravimetric method. Other high-precision methods to determine actual *evapotranspiration* (ET) are energy balance and turbulent correlation (Eddy correlation). However, due to their high economic cost and the need for fairly large-sized plots, weighing lysimeters and turbulent correlation methods are only used with the purpose of generating new methods, and for testing and adjusting existing models (López et al., 1991; Jiyane/Zermeño, 2003; Sammis et al., 2004).

In 1975 the *Food and Agriculture Organization* (FAO) of the United Nations proposed that the term "reference evapotranspiration" (ET_0) be used to describe a reference crop's (grass or alfalfa) water demand as a climate condition effect which, integrated with a series of crop and soil factors, is used to estimate *ET* (Doorenbos/Pruitt, 1975; Jensen et al., 1990; Smith, 1991), to the extent that nowadays there are numerous empirical and semi-empirical equations which may be used, although most of them require previous calibration in order to define their usefulness at a local level (López et al., 1991; Pérez J. P./Castellví, 2002; López et al., 2006). Among these semi-empirical mathematical models, the one developed by Penman-Monteith (Penman-Monteith FAO, 1956) is widely used to estimate ET_0 and subsequently manage irrigation, due to the fact that it has been widely accepted by the world scientific community and has been proposed by the FAO as the standard method for calculating ET_0 from climate information (Allen et al., 1998; Allen et al., 2005).

Direct *ET* and ET_0 measurements have been made in very few sites in Mexico because, unfortunately, there are only about three lysimeters installed and working (Ojeda, 1999; Villaman et al., 2001). Meanwhile, direct field determination by means of turbulent correlation has recently been used more frequently in very detailed studies (Moguel et al., 2001; Jiyane/Zermeño, 2003). On the other hand, other work designed to improve irrigation water planning and use – based on *ET* as a variable to be measured in daily periods for soil-water balance modelling – have been reported by Mundo and Martínez (2002) for Irrigation District 05 (Delicias, Chihuahua) and by Ojeda (1999) for Irrigation District 075 (El Fuerte, Sinaloa). With these, it has become possible to achieve savings of up to 30 per cent of water per surface unit with field-validated parameters (Sifuentes et al., 1999).

Further important work has been reported by Catalán et al. (2007); however, unlike the other work mentioned, this proposes a computer program to calculate water demand in various irrigation districts of Mexico, based on *ET* obtained from historical climate data. In accordance with these, as of 2005 the *Na-*

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tional Centre for Disciplinary Research on Water-Soil-Plant-Atmosphere Relationships (CENID RASPA, INIFAP) installed a climate monitoring system by telemetering land linking three autonomous weather stations in a network. Such stations are located at different sites in the Nazas River basin, with the purpose of monitoring the weather environment and having information available for various applications, among which has been the determination of *ET* as the main variable for describing climatology and irrigation water management: in the short term, for the pecan crop (6,375 ha) and, later on, for forage crops (in the case of alfalfa, 31,739 ha).

For describing the climatology of particular zones, the CENID RASPA network is evidently insufficient, both because of its size and because of the time it has been operating, since an observational analysis of over 30 years is required. Therefore, this can only be achieved with weather data recorded by conventional weather stations (e.g. the National Meteorological Service stations), although these are inconvenient because of the limited availability of observed weather variables, and it is in this sense that the interest of the CENID RASPA network lies. Based on the above, the object of this chapter is to estimate reference evapotranspiration (ET_0) in two sub-basins of the Nazas River from standard weather data, using the Penman-Monteith FAO, the Doorenbos-Pruitt, and the Hargreaves-Samani mathematical (1985) models, and to compare them with the data observed in the A-type tank.

13.2 The Nazas River Basin

The Nazas River basin is a hydrologic region with 36 main watersheds, located in north-central Mexico at a latitude of 23° to 27° N and a longitude of 106° to 102° W (figure 13.1). This watershed comprises 71,906 km^2 in surface area, and 95 per cent of the water resources produced there are used for agricultural production (mainly for crop irrigation), a highly controversial issue as the water resource is nowadays being excessively exploited.

Researchers from CENID RASPA of INIFAP, in collaboration with the French *Institute of Scientific Research for Development in Cooperation* (ORSTOM), currently known as the IRD (*Institut de Recherche du Développement*), conducted studies which have allowed us to demarcate the Nazas basin into three main sub-regions, based on annual precipitation analysis using the regional vector method, and also based on major component analysis, with precipitation being the dependent variable and altitude, longitude, and vegetation density as independent variables (Decroix et al., 1997; Decroix et al., 2004). These sub-regions are as follows:

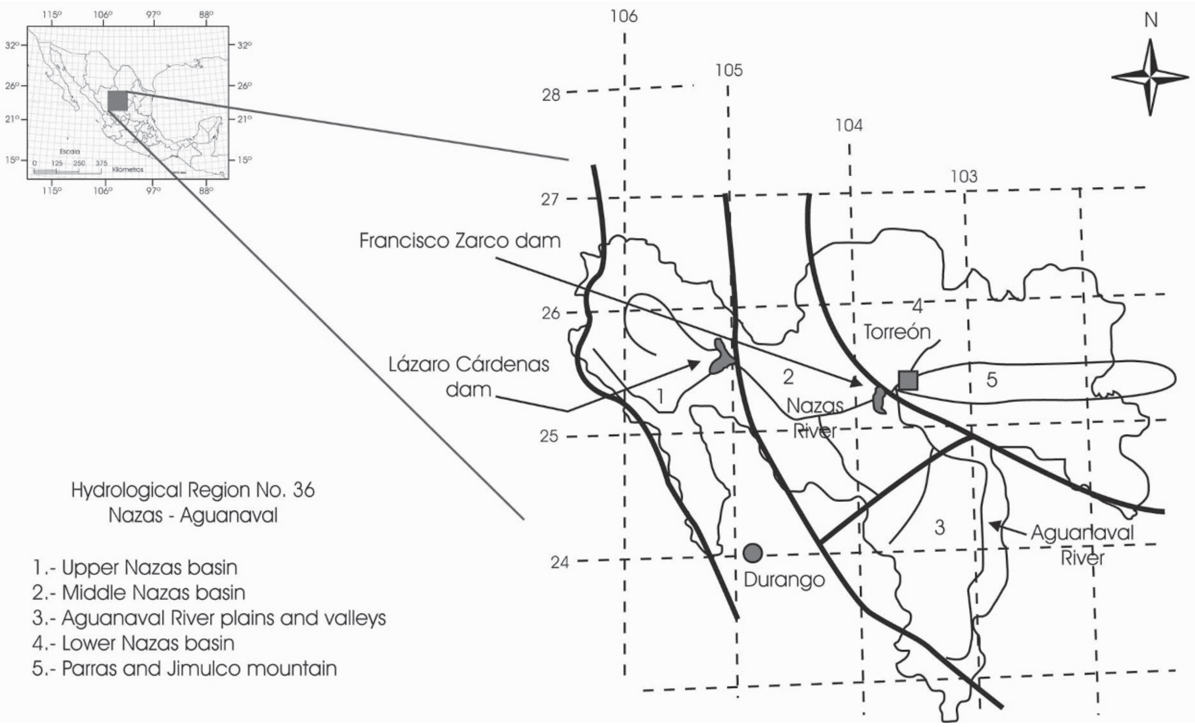
- The *Upper basin* starts in the Western Sierra Madre mountains in the state of Durango, and is classified as a sub-humid water-producing and -storing zone (this is where the Lázaro Cárdenas dam is located and obtains its water supply), with the highest vegetation indexes and over 500 mm average annual precipitation, generating 85 per cent of all run-off.
- The *Middle basin*, with a 300 to 500 mm mean annual precipitation generates only 15 per cent of all run-off and is considered as a semi-arid water storage, conveyance and resource management zone (this is where the Francisco Zarco dam is located) towards the lower Nazas River basin. Its limits may be defined as lying between the Francisco Zarco and the Lázaro Cárdenas dams.
- The *Lower basin* is located beyond the Francisco Zarco dam, downstream to the Mayrán Lake, with under 300 mm average annual precipitation. It is classified as an arid zone with water consumption for agricultural production from the upper and middle basins and water extraction from deep wells. Naturally, it is in this sub-basin that the water problem is at its greatest, with serious water management issues, excessive exploitation of aquifers, and accelerated diminishment of water quality.

Given the above, it is necessary to complete the characterization of the sub-regions with climate information. Therefore, the instrumentation of the basin is very convenient with respect to hydro-climatic applications (dry spells and their impact on the environment and on agricultural production) as well as to agro-climatic applications (water availability, demand, planning and management for agricultural activity, application of water saving technologies for irrigation, and crop selection, in the case of the lower basin).

13.3 Materials and Methods

Autonomous weather stations were the instruments used to monitor the climate for estimating ET_0; these stations were distributed as follows (figure 13.2). Two weather stations were installed in the lower basin: a Davis station, in standard reference crop conditions,

Figure 13.1: Nazas River Basin. **Source:** Adapted from Decroix et al. (2004).



and a Motorola station, the condition of which remains non-standard and therefore is not analyzed in this chapter. The first is located at the geographic coordinates: 25º35’18.090”N, 103º27’01.523”W, and 1129 m (CENID RASPA), while the second is at 25º37’02.136”N, 103º24’11.952”W, and 1126 m (at P.P. Las Villas, in Torreón, Coahuila). An Adcon station was installed in the middle basin and for standard reference crop conditions, at 25º14’43.928”N, 104º07’06.230”W, and 1243 m (P.P. Santa Bárbara, Nazas, Durango).

The Davis and Adcon stations are equipped with electronic sensors of the same brand, and the Motorola station has Decagon ECJ20 sensors. These sensors measure air temperature, atmospheric moisture, wind speed and direction, solar radiation, and precipitation at 2 metres above ground surface, and another sensor measures soil temperature at a 30 cm depth. All stations were programmed to record climate variables in one-minute periods and to consider the average of 15 recordings, i.e. every 15 minutes, to be stored in a database pertaining to each station. Subsequently, the information was requested through a computer program connecting the stations in a telemetering network, via radio frequency and at 15-minute intervals in the case of the Davis and Motorola stations, while the Adcon station data were obtained via modem, at twenty-four hour intervals. This computing system, which permits real-time monitoring, storage, use, and observation of climate variables occurring at each study site, was developed and installed in a central computer located at the CENID RASPA facilities (Ochoa, 2006).

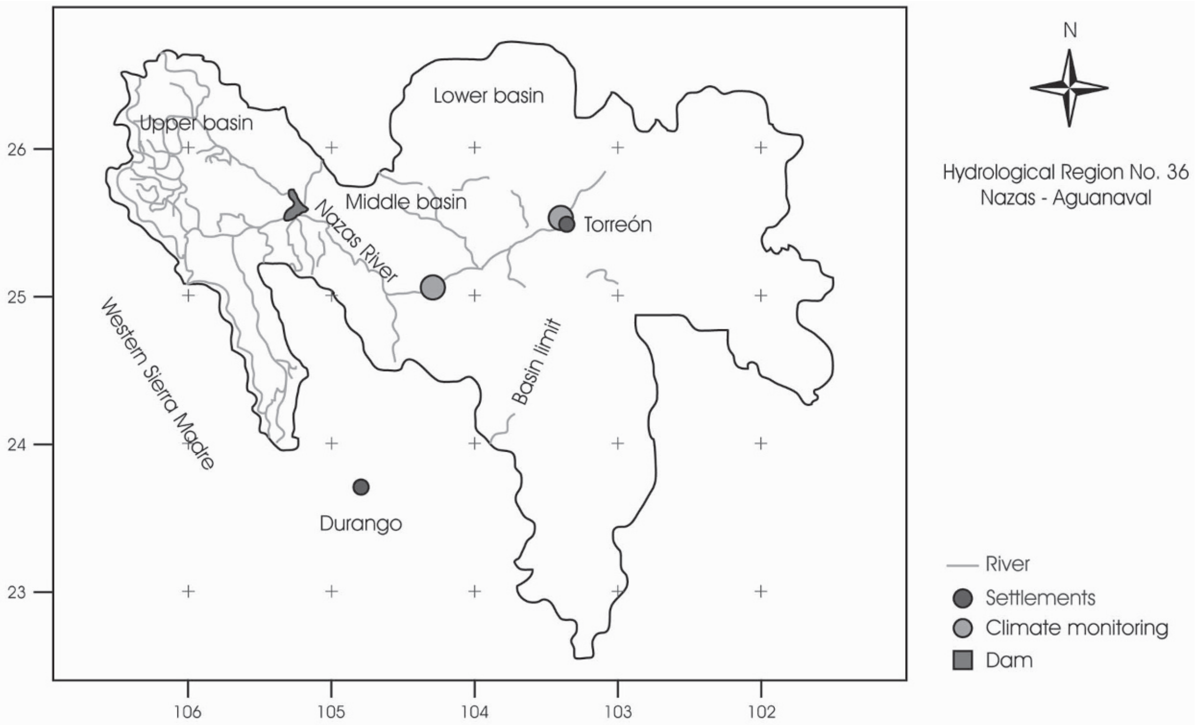
At the same site where the Davis station is located, there is an A-type evaporimeter tank (10 metres distant from the station), which was used to measure daily evaporation at 8:00 a.m. and taking into account also the days with precipitation, and to subsequently calculate the ET_0. Tank structure and dimensions, as well as site conditions, complied with FAO standard specifications (Allen et al., 1998).

13.4 Evapotranspiration Estimation Methods

The major inconvenience when measuring evapotranspiration at a regional scale and at a basin level is that any direct measurement technique is relatively expensive, hence the importance of proving the usefulness of semi-empirical models for a particular zone where climate variable data are available.

Climate information recorded at the stations located in the lower and middle basins was used to estimate ET_0 on a daily basis by the Penman-Monteith

Figure 13.2: Spatial distribution of automated weather stations in the Nazas Basin. **Source:** Authors' research data.



FAO, Hargreaves-Samani, and Doorenbos-Pruitt equations; then, a correlation was made with regard to Penman-Monteith FAO. Next, for the lower basin this study added ET_0 calculation on a daily basis from evaporation data and using the equation proposed by Cuenca (1989). Afterwards, a statistical comparison was performed between the ET_0 monthly average values obtained by the weather stations and the calculated values from the A-type tank. For this purpose, statistical indices were applied as correlation coefficient and systematic error or bias (*Bias* in equation 1), to measure the linear relationship between two quantitative variables and the model's tendency to underestimate or overestimate a variable,

$$Bias = \frac{1}{n}\sum\left(Q_{obs} - Q_{est}\right) \tag{1}$$

where Q_{obs} represents the observed value and Q_{est} the estimated value.

13.4.1 Penman-Monteith FAO Method

The Penman-Monteith FAO equation is the most precise available model. Variables used in this equation are solar radiation, air temperature, relative humidity and wind speed at 2 metres above the ground surface (Allen et al., 1998),

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2}$$

where ET_0 is the reference evapotranspiration [mm d^{-1}], R_n is the net radiation at crop surface [MJ m^{-2} d^{-1}], G is the soil heat flux density [`MJ m^{-2} d^{-1}], T is the mean air temperature [ºC], u_2 is the wind speed recorded at a 2-metre height [m s^{-1}], e_s is the saturated vapour pressure [kPa], e_a is the vapour pressure [kPa], e_s-e_a is the saturated vapour pressure deficit [kPa], is the slope of the vapour pressure curve [kPa ºC^{-1}], and γ is the psychrometric constant [kPa ºC^{-1}].

13.4.2 Doorenbos and Pruitt Method

The required climate variables are air temperature, relative humidity and wind speed during daylight hours, a and b coefficients of climate calibration as a function of relative humidity and wind speed during daylight hours, and a f_e factor as a function of the site elevation above sea level (Doorenbos/Pruitt, 1977),

$$ET_0 = f_e\{a + b[p(0.46 * T + 8.13)]\} \tag{3}$$

where ET_0 is the reference evapotranspiration [mm d^{-1}], f_e is an adjustment factor for the elevation above sea level, a and b are climate calibration coefficients, p is the annual daily mean insolation percentage, and T is the mean temperature [ºC].

13.4.3 Hargreaves and Samani Method

Inasmuch as its application demands air temperature and extraterrestrial solar radiation data (Hargreaves/ Samani, 1985), this model represents a major option when attempting to process historical climate information, in which solar radiation is frequently unavailable from domestic weather station network data. However, for the same reason, namely that this model uses few variables, it is necessary to evaluate its usefulness at a regional and local level,

$$ET_0 = 0.0023(t_{med} + 17,78)R_0 * (t_{\max} - t_{\min})^{0.5} \quad (4)$$

where ET_0 is the reference evapotranspiration [mm d^{-1}], t_{max} is the daily maximum temperature [ºC], t_{min} is the daily minimum temperature [ºC], t_{med} is the daily mean temperature [ºC], and R_0 is the extraterrestrial solar radiation [mm d^{-1}].

13.4.4 A-Type Evaporimeter Tank Method

Daily evaporation data observed in the A-Type Evaporimeter Tank can be expressed in terms of ET_0 data by using the following formula:

$$ET_0 = K_p E_{pan} \quad (5)$$

where ET_0 is the reference evapotranspiration [mm d^{-1}], E_{pan} is the evaporation observed in the tank [mm d^{-1}], and K_p is the tank coefficient. *Kp*, derived from the equation proposed by Cuenca (1989), was employed to calculate ET_0 with this method, using average values of wind speed and relative humidity at the tank site.

This method has confirmed its practical value, and it has been successfully applied to calculate ET_0, since evaporation measurement incorporates the effect of radiation, wind, temperature, and humidity at a specific site. In some experimental works, evaporation values measured in the A-type tank, affected by their corresponding correction factors, have been used to calculate the irrigation water volume to be replaced in crops (Godoy/López, 1997; Tijerina, 2000; González/ Hernández, 2000).

13.5 Results and Discussion

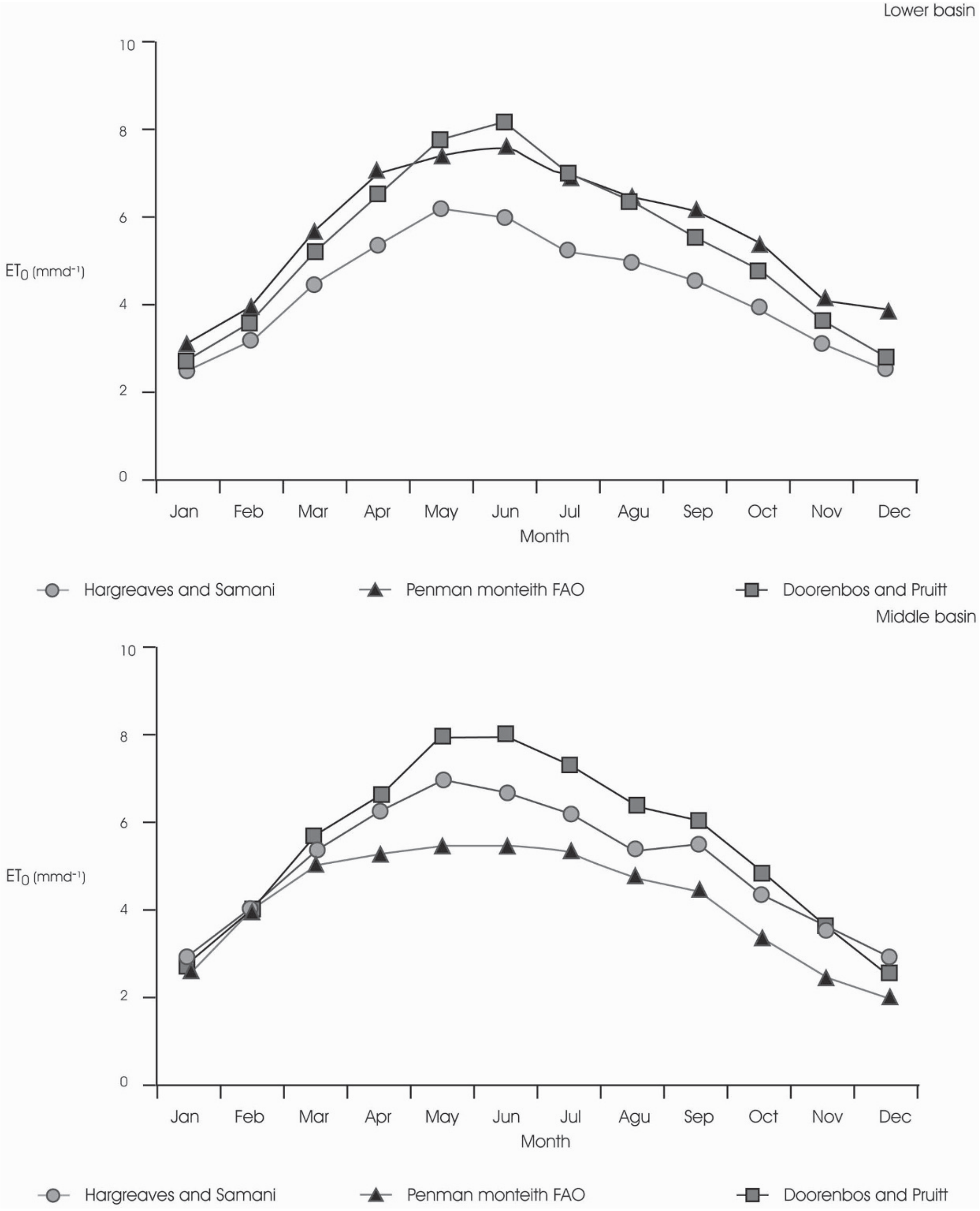
13.5.1 Reference Evapotranspiration

Climate information from three observation cycles (years 2005, 2006 and 2007) was used to estimate ET_0 in the lower and middle Nazas River basins; these data were recorded by the autonomous stations already described for each sub-region. Estimations in daily periods were then made, using the Penman-Monteith FAO, Doorenbos-Pruitt and Hargreaves-Samani models. However, for the purpose of data appreciation, these are shown in daily average values per month, after having averaged all three observed cycles. Subsequently, a simple correlation was performed between ET_0 obtained with the Doorenbos-Pruitt and the Hargreaves-Samani methods, and that obtained by the Penman-Monteith FAO model.

Figure 13.3 shows the results for our study sites. In this figure it is possible to observe an evident difference between the lower and middle basins using the Penman-Monteith FAO equation, and not a very noticeable one with the Doorenbos-Pruitt equation, with evapotranspiration in the lower basin being greater. But with the Hargreaves-Samani equation it is also possible to appreciate a difference, albeit in the opposite sense: i.e., with evapotranspiration in the middle basin being greater. The reason for this result may correspond with two interrelated situations: the scarce climate information used by the method and/ or its strong reliance on (extraterrestrial) solar radiation based on the site's geographic location, which therefore does not involve the orographic environment effect.

The lower basin (Davis station) presents similar ET_0 tendency patterns to the Doorenbos-Pruitt and Penman-Monteith FAO methods, showing minimum values at the beginning of the cycle (January) and maximum values at its middle (June), at a rate of 3 and 8 mm d^{-1} respectively, with this last value decreasing to a value between 3 and 4 mm d^{-1} at the end of the cycle (December). By contrast, the values obtained with the Hargreaves-Samani method are 2.5 (at the beginning and the end of the cycle) and 6.2 4 mm d^{-1} (at its middle) as minimum and maximum values, correspondingly. There is a time gap (May) in the maximum evapotranspiration value, a period which is signalled as the one with the greatest extraterrestrial solar radiation incidence. However, all three models coincide in the critical period, with the highest evapotranspiration being the months of April to September. Also, during this period a considerable difference can be

Figure 13.3: *ET_0* behaviour, average of three observation cycles (years 2005, 2006 and 2007), in the lower and middle Nazas River Basins, using different methods. **Source:** Authors' research data.



observed in the results from all three models (up to 1.8 mm d^{-1}).

The middle basin (Adcon station) presents tendency patterns similar to those presented by the lower basin, with the critical period being April to Septem-

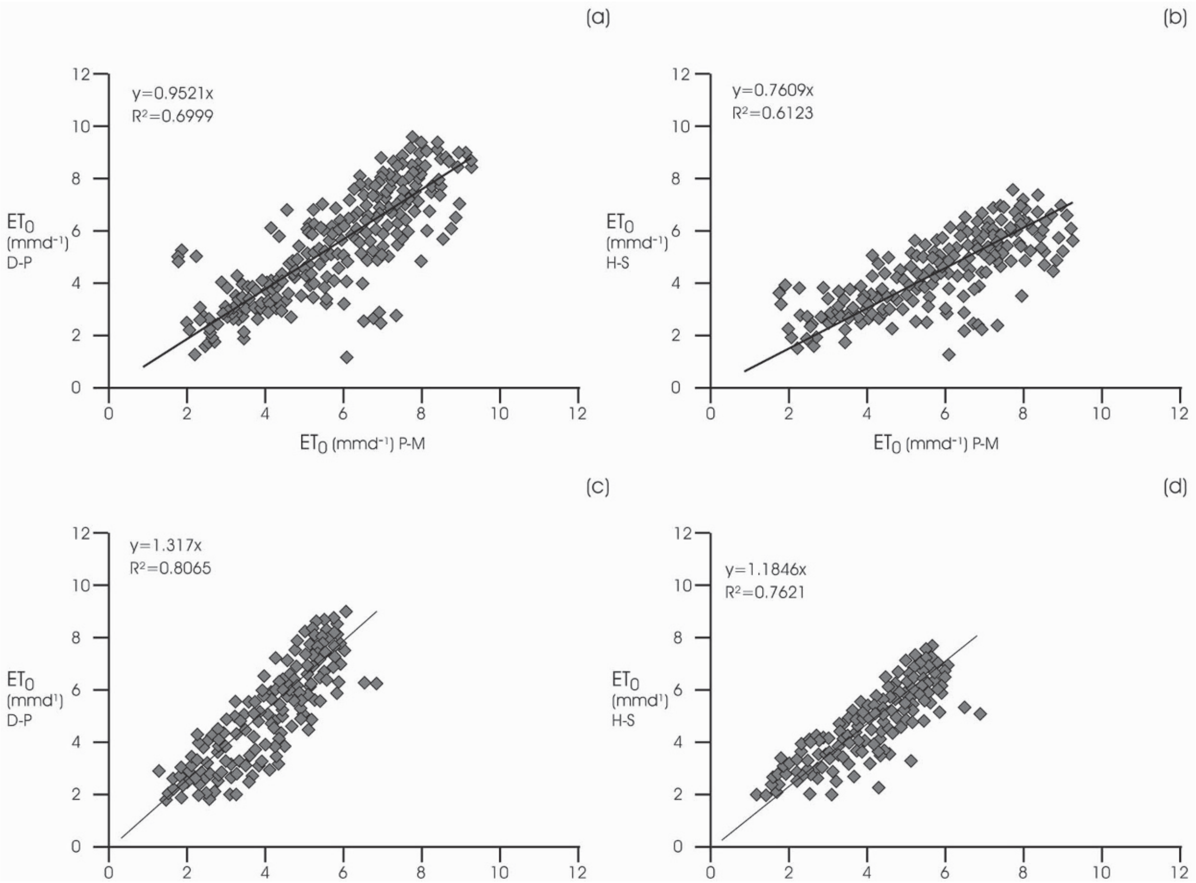


Figure 13.4: Estimate of ET_0 using the methods of Doorenbos-Pruitt 'D-P' and Hargreaves-Samani 'H-S', compared with ET_0 using the Penman-Monteith FAO method 'P-M', in (a) and (b), respectively, for the lower basin, and (c) and (d), using the same framework, for the middle basin for the 2005, 2006, and 2007 period average. **Source:** Authors' research data.

ber, with evapotranspiration discrepancy in the results from all three models for this same period, but with a greater contrast (up to 2.5 mm d^{-1}).

It is evident that the Penman-Monteith FAO model presented a greater, somewhat 'logical', sensitivity to change, due to the fact that climate variables such as temperature, wind speed, and solar radiation evidenced higher values in the lower basin as compared to those in the middle basin.

In addition, a correlation was performed between these models in order to note the usefulness of those with lower demand for climate variables, as compared to the one requiring most climate variables defining evapotranspiration. In this case the Doorenbos-Pruitt and Hargreaves-Samani models were compared with the Penman-Monteith FAO model. Figure 13.4 shows the results, indicating acceptable correlations, with the Pearson correlation coefficient being 0.69 and 0.61 for the lower basin, and 0.80 and 0.76 for the middle basin with the Doorenbos-Pruitt and Hargreaves-Samani models, as compared to the Penman-Monteith FAO method, respectively. The Pearson coefficients are slightly higher for the middle basin, due to the fact that there is a minimum difference during the first months of the period (January, February, and March).

13.5.2 Comparison of Methods

The comparison of the methods was performed solely for one observation cycle (2005) and during the critical or high evapotranspiration period, covering the months of May, June, July, and August. It has to be considered that all three models used evidence from the maximum water demand during this period, and it is also this period that presents a marked difference in the estimation of ET_0 with all three models. This comparison consisted in performing a correlation of ET_0 monthly average values, determined by the A-type evaporimeter tank (equation four) against

Table 13.1: Average monthly ET_0 values in the lower basin during the maximum water requirement period (May–August). **Source:** Authors' research data.

Method	ET_0 (mm d^{-1}) monthly average				**Correlation Coefficient**	**Bias %**
	May	**June**	**July**	**August**		
A-type tank	6.902	8.001	7.571	6.166	-	-
Penman-Monteith	7.817	8.297	7.790	6.345	0.913	+5.614
Doorenbos-Pruitt	8.372	9.821	7.912	6.794	0.861	+14.860
Hargreaves-Samani	6.339	6.696	5.447	5.109	0.646	-17.625

monthly average values obtained by the Penman-Monteith FAO, Doorenbos-Pruitt, and Hargreaves-Samani models.

The results are presented in table 13.1. This table shows that the Penman-Monteith FAO and the Doorenbos-Pruitt methods overestimate ET_0 by 5.61 and 14.86 per cent, with a *correlation coefficient* (cc) of 0.91 and 0.86, correspondingly. On the other hand, the Hargreaves-Samani method underestimates it by 17.62 per cent, with a cc of 0.74 during the period analysed. According to De Juan (1993) the correlation coefficients obtained may be considered as acceptable when referring to very high correlations. The obtained bias and cc are noteworthy evidence that the Penman-Monteith FAO model is highly precise for this region, followed by the Doorenbos-Pruitt model, and finally by the Hargreaves-Samani model.

13.6 Conclusions

Except for Hargreaves-Samani, the models used the evidence of a higher reference evapotranspiration in the lower Nazas River basin as compared with the middle basin, confirming that this corresponds to two completely different conditions, more clearly during the March–September period. For water management this means a greater demand for water by any crop established under the lower Nazas River basin climate conditions.

Among the methods analyzed regarding the evaporimeter tank, it may be presumed that the Penman-Monteith FAO method is highly precise in estimating reference evapotranspiration in the lower basin. However, when not enough variables are available, it is also suggested that the Doorenbos-Pruitt method should be used as a second option, and as a last alternative the Hargreaves-Samani model, although in this case it is suggested that studies at a local level be also performed in order to calibrate this model and improve its usefulness.

References

Allen, R.G., I.A. Walter, R. Elliot, T. Howell, D. Itenfisu, and M. Jensen (2005), "The ASCE Standardized Reference Evapotranspiration Equation", in *American Society of Civil Engineers Environmental, Water Resource Institute (ASCE-EWRI)*, pp. 7–9.

Allen, R., L. Pereira, D. Raes, M. Smith (1998), "Crop evapotranspiration", FAO Irrigation and Drainage Paper 56, FAO, Rome.

Arora, V.K. (2002), "The Use of the Aridity Index to Assess Climate Change Effect on Annual Runoff", in *Journal of Hydrology*, vol. 265, pp. 164–177.

Catalán, V., I. Sánchez, M. Villa, M.A. Inzunza and S.F Mendoza (2007), "Programa para calcular demandas de agua y calendarizar el riego de los cultivos", in *Folleto Técnico* no. 7, Gomez Palacio, CENID RASPA, INIFAP, pp. 1–13.

Catalán, V., P.J. Mungía, L. Villa, G. Zermeño, M.A. Inzunza, L.A. Roman and A.J. Arreola (2008), "Flujos de agua y CO_2 en nogal", XVI simposium internacional nogalero, Torreon, CENID RASPA, INIFAP.

Cuenca, R.H. (1989), "Irrigation System Design: An Engineering Approach", Englewood Cliffs, NJ, Prentice Hall.

De Juan, J. (1993), *Agronomia del riego*, Madrid, Mundi-Prensa.

Descroix, L., J.F. Nouvelot and J. Estrada (1997), "Geografía de lluvias en una cuenca del Norte de México: Regionalización de las precipitaciones en la Región Hidrológica 36", *Folleto Científico* no. 10, Gomez Palacio, CENID RASPA, INIFAP, Paris, ORSTOM, pp. 52–123.

Descroix, L., J.L. González and J. Estrada (2004), *La sierra madre occidental, un château d'eau menace*, París, L'Institut de recherche pour le développement, pp. 132–149.

Dinpashoh, Y. (2006), "Study of Reference Crop Evapotranspiration in I.R. of Iran", in *Agricultural Water Management*, vol. 84, no. 1-2., pp. 123-129.

Doorenbos, J. and W. O. Pruitt (1977), "Crop Water Requirements", in *Irrigation and Drainage*, Paper no. 24, Rome, FAO.

Er-Raki, S., A. Chehbouni, N. Guemouria, J. Ezzahar, S. Cava, G. Boulet and L. Hanich (2009), "Citrus Orchard Evapotranspiration: Comparison between Eddy Covariance Measurements and the FAO-56 Approach Estimates", in *Plant Biosystems*, vol. 143, no. 1, pp. 201-208.

Godoy A., and J.C. López (1997), "Patrón de extracción y requerimientos de agua en diferentes etapas fenológicas en el nogal", in *Revista Interamericana Terra*, vol. 15, pp. 1-6.

González M.A. and L. B. Hernández (2000), "Estimación de las necesidades hídricas del tomate", in *Revista Interamericana Terra*, vol. 17, no. 4, pp. 45-50.

Hargreaves, G.H. and Samani (1985), "Reference Crop Evaluation for Temperature", in *Applied Engineering in Agriculture*, no. 1, pp. 96-99.

Jacobs, C., G.J. Roerink and A. Hammani (2008), "Crop Water Stress Detection from Remote Sensing Using the SSEBI-2 Algorithm: A Case Study in Morocco", in *XIII World Water Congress, Montpellier, France*.

Jensen, M.E., R.D. Burman and R.G. Allen (1990), "Evapotranspiration and Water Irrigation Requirements", Committee on Irrigation Water Requirements, Irrigation and Drainage Division of ASCE, New York, American Society of Civil Engineers, manual no. 70, pp. 332.

Jiyane, J. and A. Zermeño G. (2003), "Aplicación del enfoque de evapotranspiración a equilibrio en la agricultura de riego en zonas áridas", in *Revista Agrociencia*, vol. 37, no. 6, pp. 553-563.

López, E.J, Ch. Tijerina, A.G. Haro and R.R. Arteaga (1991), "Calibración de fórmulas de evapotranspiración mediante un cultivo de alfalfa como referencia en el área de Montecillo, Estado de México", in *Agrociencia*, no. 2, pp. 55-77.

López, U.R., F. Martín de Santa Olalla, C. Fabeiro and A. Moratalla (2006), "An Evaluation of Two Hourly Reference Evapotranspiration Equations for Semiarid Conditions", in *Agricultural Water Management*, vol. 86, no. 3, pp. 277-328.

Moguel, O.E., Ch. Tijerina, A. Quevedo, G. Crespo and G. Haro (2001), "Evapotranspiración y balance de energía en el cultivo de alfalfa", in *Agrociencia*, vol. 35, no. 1, pp. 13-21.

Mundo, M., and P. Martínez (2002), "Sistema computarizado para la gestión del agua en sistemas de riego por gravedad en México", in *Ingeniería del agua*, vol. 9, no. 2. pp. 171-181.

Ochoa del T., D. (2006), "Estaciones meteorológicas en un sistema informático en red para la agricultura de precisión", Master thesis, Torreon, Technological Institute of the Laguna (Instituto Tecnológico de la Laguna), September, pp. 2-40.

Ojeda, B.W. (1999), *Pronóstico del riego en tiempo real*, Cuernavaca, Instituto Mexicano de Tecnología del Agua (IMTA), pp. 60-80.

Penman-Monteith and FAO (1956), "Chapter 2 - FAO Penman-Monteith equation", at: <http://www.fao.org/docrep/x0490e/x0490e06.htm>.

Pereira, A., S. Green and N.A.V. Nova (2006), "Penman-Monteith Reference Evapotranspiration Adapted to Estimate Irrigated Tree Transpiration", in *Agricultural Water Management*, vol. 83, pp. 153-161.

Pérez, J.P. and F. Castellví (2002), "Análisis de la evapotranspiración a escala local y regional en Cataluña", in *Ingeniería del agua*, vol. 9, no. 1, pp. 59-71.

Salinas, Z., D. Llluche, S. Hernández and D.B. Lluche (1998), "La aridez en el norte de México. Un análisis de su variabilidad espacial y temporal", in *Atmósfera*, vol. 11, pp. 29-44.

Sammis, T.W., J.G. Mexal and D. Miller (2004), "Evapotranspiration of Flood-Irrigated Pecans", in *Agricultural Water Management*, vol. 69, pp. 179-190.

Sifuentes I., B.W. Ojeda and A.H. Gómez (1999), "Calibración de parámetros de cultivo en papa para la calendarización del riego en tiempo real bajo dos sistemas de riego en el DR-075, Río Fuerte, Sinaloa", IX Congreso Nacional de Irrigación, Culiacán.

Smith, M. (1991), *Report on the Expert Consultation on Procedures for Revision of FAO Guidelines for Prediction of Crop Water Requirements*, Rome, FAO.

Tijerina, Ch. (2000), "Requerimientos hídricos de los cultivos bajo sistemas de fertirrigación", in *Revista Interamericana Terra*, vol. 17, no. 3, pp. 237-244.

Villaman, P.R., Ch. Tijerina, N.A. Quevedo and P.G. Crespo (2001), "Comparación de algunos métodos micrometeorológicos para estimar la evapotranspiración, en el área de Montecillo, México", in *Revista Interamericana Terra*, vol. 19. no. 3, pp. 281-291.